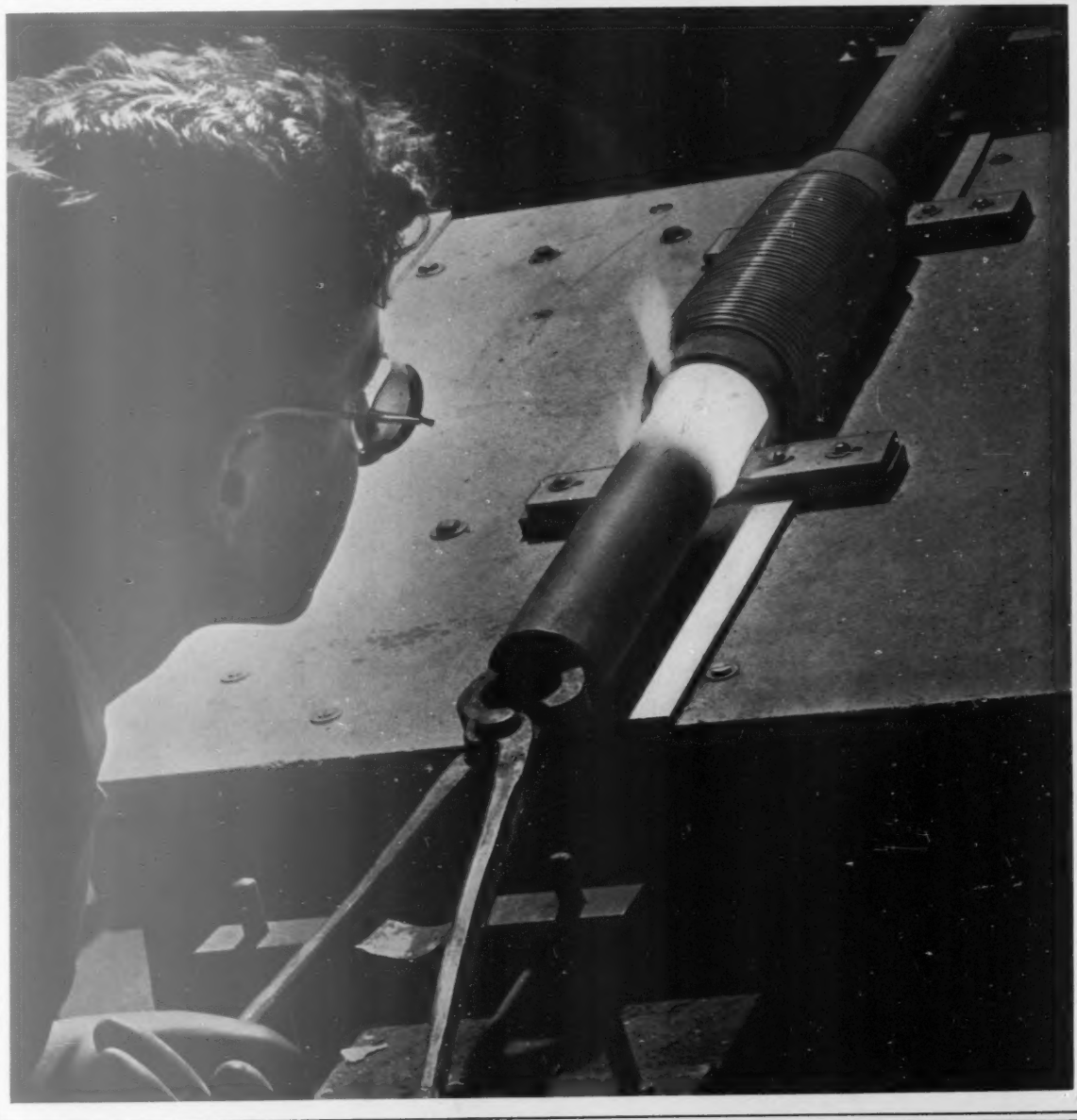
ALLIS-CHALMERS

Electrical REVIEW



March 1945

YOU SHOULD KNOW THESE IMPORTANT DIFFERENCES BETWEEN RECTIFIERS:

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☛ That means that with Excitron there are no ignition impulses to be synchronized with main anode voltage. Tubes don't require re-ignition at start of each positive half-cycle.

☛ Only Excitron has an excitation anode in fixed position above and not touching hot mercury.

☛ Thus, the anode cannot be affected by any coating or turbulence on the surface of the mercury. There is no critical location of anode which might require external adjustment or special maintenance.

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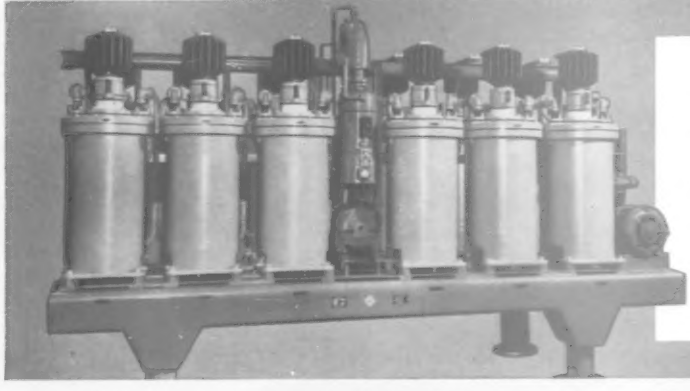


ALLIS-CHALMERS engineers *introduced* mercury arc rectifiers to American industry.

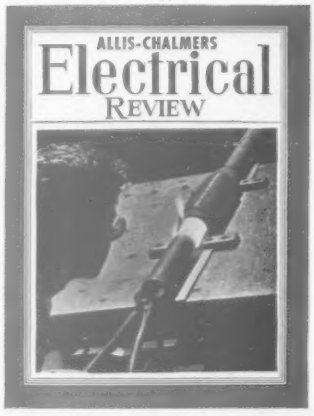
Today, their pioneering pays off in the advanced, *time-proven* design of Excitron. You get exceptionally efficient, trouble-free operation.

Consider the economical Excitron for all power conversion from 250 volts up. Allis-Chalmers, Milwaukee 1, Wis.

ALLIS-CHALMERS EXCITRON MERCURY ARC RECTIFIERS

EFFICIENCIES of induction heating units, listed on pages 4 and 5 as "heating" efficiencies, are actually CONVERSION efficiencies.

INDUCTION HEATING operation pictured on page 6 shows an INDUCTION furnace, from which melted metal is transferred by ladle to the centrifugal casting machines in the background.



ANNEALING stainless steel at 1950 degrees Fahrenheit with new induction heating equipment is high-speed, efficient. In experimental setup pictured on the cover, the object moves rapidly through the inductor, comes out while hot. Induction heating, newly revitalized metal-working tool, is reviewed at length on following pages of this issue.

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ALLIS-CHALMERS Electrical REVIEW

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QUICKER, EASIER READING is aim of the new format adopted with this March issue of the Allis-Chalmers **ELECTRICAL REVIEW**. Preceding design identified the **REVIEW** for eight years, now bows to a treatment we hope you will find more interesting, more dramatic.

Induction Heat Works Metal Magic!

DR. S. H. MORTENSEN, *Chief Engineer*
Electrical Department, Allis-Chalmers Mfg. Co.

ELECTRONIC induction heating—a new tool with a great future in the concept of many — already has quite a past. Historically, induction heating has been utilized for decades. Practically, it is already well established as an industrial tool and, in fact, is already in the same category with such a metal-working standby as electric welding.

Within the last few years interest in induction heating possibilities has grown to proportions actually comparable to the popularity of "electronics" itself. Hundreds of different products are now being brazed, soldered, annealed, hardened, melted or induction heated for other metal processes. Metal working plants are building special laboratory and production facilities to conduct induction heating operations. Electrical utilities and manufacturers are assuming the responsibility for keeping power users acquainted with developments in new equipment and the possibilities for new applications.

Electronic induction heating is no longer handicapped by the long standing opinion that it is "too expensive" and just a "marvel of the future."

The popularity of induction heating is due to several advantages in comparison to other means of heating, some of them being listed as follows:

1. Speed of heating metals with consequent reduction of oxidation and scaling.
2. Ability to heat limited parts or surfaces of a metal piece instead of the entire piece.
3. Use of power for heating only when desired, without necessity of maintaining furnace temperature continuously.
4. When melting, thorough mixing of the alloys due to "stirring effect."
5. No contamination of the charge by fuel gases.
6. Better working conditions for the operators than with fuel or gas-fired furnaces.

With advantages like these, the newly revitalized induction heating process is almost certain to be utilized throughout the metal-working industry.

As an electrical process, induction heating has few limitations. Fundamentally, it requires alternating current . . . at any frequency from the commercial 60 cycles to millions of cycles per second. Since the great majority of induction heating applications require higher frequencies than 60 cycles, induction heating equipment consists primarily of some type of converter which will provide the electric energy at the desired frequency. Several types of converters are available so that selection of the most suitable equipment for solving specific heating problems should be based on the required frequency, and the initial, operating and maintenance costs.

In the process the object to be heated, called the "charge," has to be electrically conductive and is placed in an alternating magnetic field produced by a conductor (for example, a solenoid) energized by a converter of suitable frequency. Voltages induced in the charge cause I^2R losses due to eddy currents and in some materials at certain temperatures hysteresis losses also occur. Induction heating is the result of these losses.

The greatest density of heat generation is at the surface layer of the charge. The ratio of heat generation declines rapidly toward the interior of the charge and is zero at its center. Increasing the frequency reduces the radial thickness of the surface layer, concentrating the generated heat still more in the surface layer. This concentration of heat generation in the surface layer of the charge is called "skin effect."[1]

In induction heating there are also important relations between frequency and efficiency of heating. For instance, efficiency does not increase with the increase in frequency of the charge if the charge is large enough. For one and the same frequency the efficiency is small for comparatively small diameters, increasing with the radius of the charge. There is, however, a limit beyond which a further increase in size of the charge will not increase inductor efficiency.

For induction heating of large masses for melting, forging, annealing, and deep surface hardening, frequencies of about 500 to 3000 cycles often yield the highest efficiencies. For small pieces, or for very thin case hardening of steel as well as brazing and soldering operations, higher frequencies from about 10,000 cycles to a million or more cycles are used.

With these relations of frequency, skin effect and heating efficiency in mind, proper selection of induction heating equipment can be made. A comparison of the available units on the basis of frequency range and approximate heating efficiency are as follows:

VACUUM TUBE CONVERTERS

Frequency 100,000 to 100,000,000 cycles.

Approximate heating efficiency 50-60 per cent.

SPARK-GAP CONVERTERS

Frequency 30,000 to 400,000 cycles.

Approximate heating efficiency 50-60 per cent.

[1] See Appendix, page 17.

KNOWLEDGE of peculiar characteristics and specific ranges of equipment now available is necessary to get the most from industry's newly revitalized tool — induction heating.

HEAT CONCENTRATION is so marked in induction heating process that this object could be grasped bare-handed immediately after it was removed from the inductor, the heated portion still being white hot. Heating is so fast that little heat escapes from area where it is actually required.

MOTOR-GENERATOR SETS
Frequency up to 10,000 cycles.
Approximate heating efficiency 65-75 per cent.

MERCURY ARC CONVERTERS
Frequency up to 1500 cycles.
Approximate heating efficiency 90 per cent.

Vacuum tube converters are peculiarly adapted to numerous high frequency induction heating applications. They are available in units from one to several hundred kilowatts output, they have no moving parts, are quiet in operation, capable of operating on a 24-hour-a-day, 7-day-a-week schedule without servicing. With the increase in life expectancy of these vacuum tubes to an average of 4000-5000 hours, maintenance costs are being lowered and now amount to about one cent per kilowatt installation and hour of use. Vacuum tube converters are discussed at greater length in this issue on page 15.

Spark-gap converters are available in units for power output from one to about 35 kw. They are usually rated in input kva and not in output kw. In the radio-frequency field they have a slightly lower initial cost per kilowatt output than the vacuum tube converter and the advantage of relative simplicity. The sparking across the gaps causes corrosion, hence periodic readjustment of the gaps is necessary.

Motor-generator sets for induction heating are available for various fixed frequencies up to 10,000 cycles.

Power output of the units range from 7.5 kw to several hundred kilowatts, with initial and maintenance costs lower than such costs for vacuum tube converters. Their relatively low frequency, however, excludes the motor-generator from use for hardening of very thin cases.

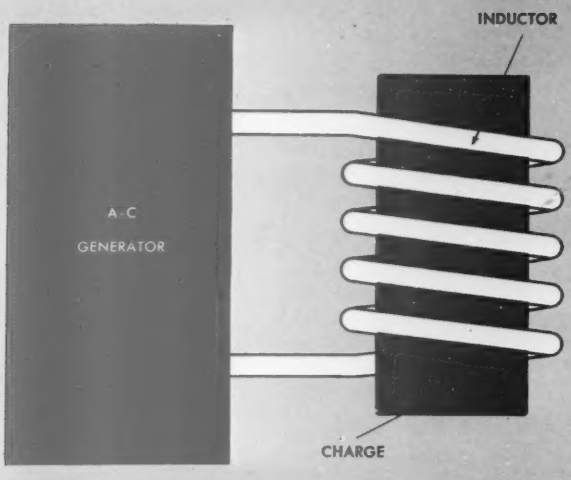
Mercury arc converters are an adaptation of the well known steel tank mercury arc rectifier, offering many advantages for induction heating, particularly in the low frequency range. Discussed in greater detail in the following article, these advantages are:

1. Higher conversion efficiency than any other type of converter for induction heating at full load. At partial loads the conversion efficiency is relatively still greater.
2. Static type equipment requiring no heavy foundations.
3. No ventilation nor air filtering apparatus required.
4. Much of the equipment is suitable for outdoor operation.
5. Quiet operation.
6. Low maintenance costs.
7. Great reliability.

Because these different types of equipment for performing induction heating operations are now available, and particularly because each type has peculiar characteristics and performs in a specific frequency range[2], knowing what the equipment will do is extremely important. Consultation with engineers who specialize in induction heating is certainly to be recommended.

[2] In the radio frequency range, dielectric heating extends the field of application for electronic equipment to a literally limitless number of nonmetallic industries. This phenomenon is further discussed on page 17.

POURING DIRECTLY INTO THE MOLD from the arc furnace crucible is possible with induction heating. This is a brass foundry, with centrifugal casting machines in the background. The new mercury arc converters are especially adapted to melting applications operating at 500-1500 cycles frequency.



IN INDUCTION HEATING the "charge" (color for emphasis only) is exposed to an alternating magnetic flux produced by an inductor energized from an a-c generator (Fig. 1).

Mercury Arc Converter

MASTERS METALS IN DEEP HEATING

DR. H. F. STORM

Rectifier Section, Allis-Chalmers Manufacturing Co.

NEWEST electronic converter for melting, forging, annealing, and deep surface hardening of larger masses is most efficient of all induction heating equipment.

A DISCUSSION of induction heating problems usually involves questions as to where, how deep, and how much heat should be created in a given object. If the object is a shaft to be surface hardened, it is obvious that it is desirable to concentrate the generated heat into a thin surface layer of the shaft. If the object, however, is a metallic charge to be molten, heat should not be concentrated in the surface layer (which may melt and even evaporate while the interior of the charge is still cold), but to apply the generated heat to as large a cross-section as possible, resulting in a more even temperature distribution.

The heat will be generated in a larger cross-section of the charge if a comparatively low frequency, for instance, 1000 cycles, is used. A recent development in power electronics, called the mercury arc frequency converter, converts 3-phase, 60-cycle power into single-phase power at a frequency of around 1000 cycles. The application of this electronic converter for induction heating, such as melting, forging, annealing and deep surface hardening of larger masses, produces a greater total efficiency than any other equipment so far known.

Frequency and heating depth

In order to understand the advantages and limitations of the mercury arc converter, it is necessary to discuss the effects of frequency with respect to depth of heating and efficiency of heating.

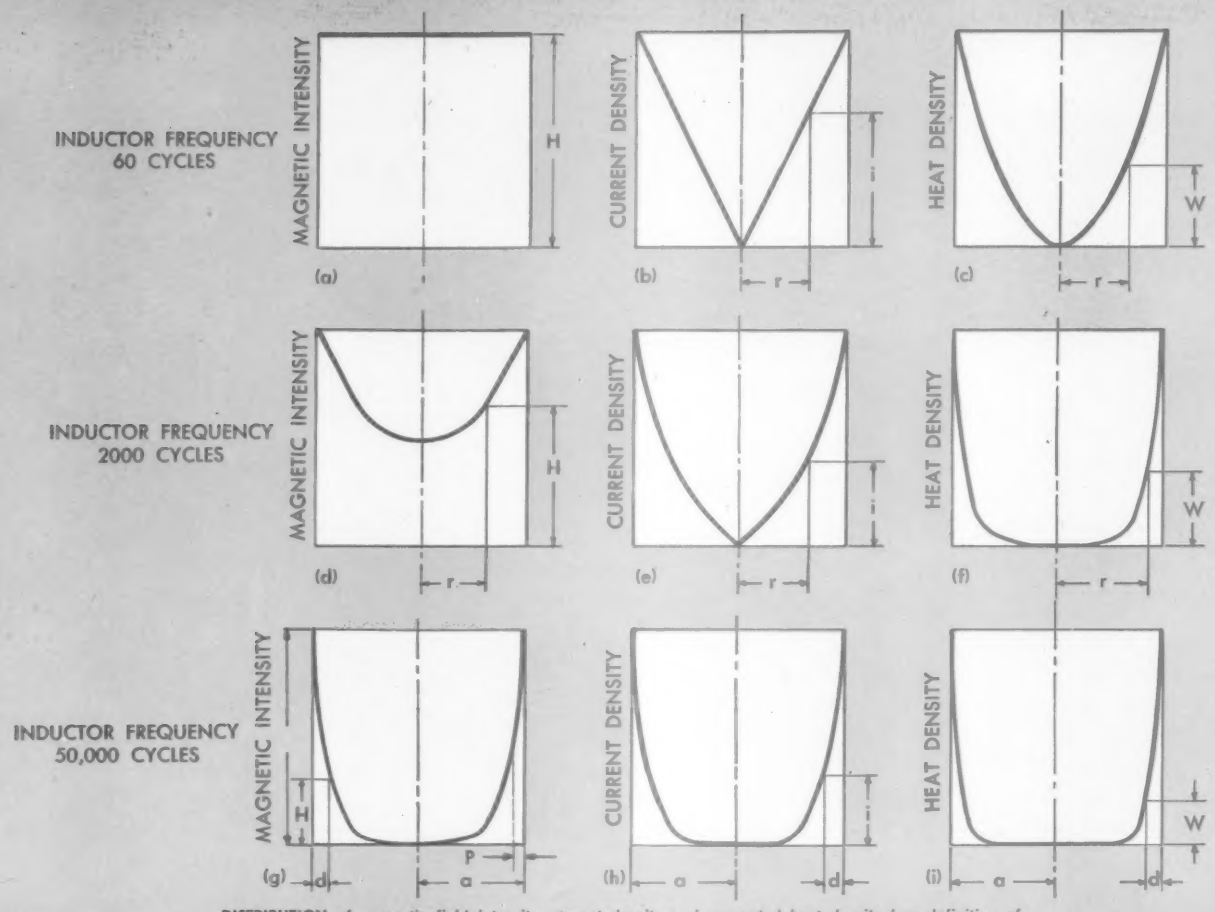
In the process, the "charge" is exposed to an alternating magnetic flux, which may be produced by a solenoid, energized from an a-c generator of suitable frequency (Fig. 1). The alternating magnetic flux induces voltages within the charge, comparable to the induction of voltages in the shorted secondaries of a multi-winding transformer. The voltages cause currents—the so-called eddy currents—to flow through the charge, producing the I^2R heating effect.

Heat may also be produced by hysteresis in the case of ferromagnetic materials below the Curie point. For a large majority of practical applications of induction heating, the hysteresis loss is negligible and will be disregarded in the following.

The distribution of magnetic field intensity, current density, and generated heat density for a round stainless steel bar one inch in diameter is shown in Fig. 2.

Inside the charge the magnetic flux induces voltages which follow circles whose centers are located on the axis of the charge and whose planes are perpendicular to the axis. The voltages are proportional to the flux they surround. If the inductor current has a frequency of 60 cycles and the magnetic intensity inside the charge is assumed constant throughout its cross-section (as in Fig 2a), the induced voltages are proportional to the square of the radius. The eddy currents are proportional to the voltages and inversely proportional to the resistance of the individual paths of the eddy currents. As voltages increase with the square of the radius r and resistance of the individual current path is proportional to r, the eddy current density increases lineally with the radius (Fig 2b).

At the center of the charge the eddy current density is zero and at the surface of the charge it reaches its highest value. The rate of heat generation is proportional to the square of the eddy current density, hence



DISTRIBUTION of magnetic field intensity, current density and generated heat density (see definition of symbols, p. 13) for a round stainless steel bar, at inductor frequencies of 60, 2000, and 50,000 cycles. (Fig. 2).

the distribution of generated heat is a parabola (Fig. 2c). The greatest density of heat generation occurs at the surface layer, which is called the skin of the charge. The ratio of heat generation declines rapidly toward the interior of the charge and is zero at its center.

According to Lenz's law, the eddy currents will produce magnetomotive forces which oppose the original distribution of the magnetic intensities, resulting in a weakening of magnetic field in the charge. In the case of an inductor frequency of 60 cycles and stainless steel charge of one inch outside diameter, the magnitude of the eddy currents is comparatively small and hence their magnetic counter-action is negligible.

Suppose the current in the inductor is kept constant but the frequency is increased from 60 to 2000 cycles. The induced voltages and hence the eddy currents will greatly increase and reach intensities which now suffice to modify markedly the original field distribution. Weakening of the magnetic field in the charge (Fig. 2d) results from the magnetomotive forces produced by the eddy currents which oppose the original distribution of the magnetic intensities. The induced voltages now decline more rapidly with decreasing radius r than in the previous case of 60-cycles (Fig. 2a). Consequently, the eddy currents (Fig. 2e) and the generated heat (Fig. 2f) also decline more rapidly toward the center of the charge, concentrating in the surface layer of the charge to a higher degree than in the case of 60-cycles (Figs. 2b, 2c).

If the current in the inductor is maintained at its previous value, but the frequency again stepped up (now to 50,000 cycles), the induced eddy currents increase to such an extent that they practically eradicate the magnetic field at the center of the charge (Fig. 2g). The result is a further intensification of eddy current generation (Fig. 2h) and of heat generation (Fig. 2i) in the surface layer of the charge, the concentration being called skin effect.

The distribution of heat generation with respect to the radius is now practically exponential (Fig. 2g, h, i). The heat which is generated in the surface layer of the thickness p comprises roughly three-quarters of the total generated heat. The thickness p gives an indication of the thickness of the surface layer, which contains the bulk of the generated heat, and p is called the depth of penetration ($p = 3570\ \sqrt{\rho/\mu f}$). Other factors remaining unchanged, the depth of penetration is inversely proportional to the square root of the frequency.

Surface hardening where very thin cases and hence a small penetration are required are typical applications for frequencies over 100,000 cycles. In applications where through heating of larger masses should be achieved—for instance, forging, annealing, deep surface hardening of shafts and melting of metals—low frequencies not only can be used, but certainly should be used, for if the same amount of heat would

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be applied at a comparatively higher frequency, overheating of the surface of the charge would result because the heat generation is constricted to a thinner surface layer. Metals at the surface may melt and even evaporate while the interior is still cool.

Efficiencies and size of charge

The efficiency of high frequency heating is the ratio between the heat generated in the charge and the energy which is taken from the supply line. This efficiency is called more specifically total or overall efficiency. The overall efficiency is the product of two factors: the inductor efficiency and the conversion efficiency. The inductor efficiency denotes the ratio between the heat generated in the charge and the amount of energy delivered to the inductor. Conversion efficiency is the ratio between the power delivered to the inductor and power from the supply line.

First, consider the inductor efficiency. Assume that frequency and current in the inductor are kept constant, but that the diameters of charge and inductor are varied simultaneously, starting with small diameters and increasing. If the diameter of the charge is doubled, for instance, then its cross-sectional area becomes four times as large, and likewise the magnetic flux and the induced voltage become four times as large. The average resistance of the eddy current path, however, remains the same because the length and the cross-section of the eddy current path have been increased by the same ratio.

The generated heat is a function of E^2/R so that the generated heat becomes 16 times as large when the radius of the charge is doubled. The generated heat increases with the fourth power of the radius of the charge, as shown in Fig. 3. The function plotted on the abscissa axis is the product of the radius of the charge and the square root of the frequency. Since the frequency is kept constant and the material of the charge remains the same, the only variable is the radius a. The ordinate axis contains a function which is proportional to the rate of heat generation.

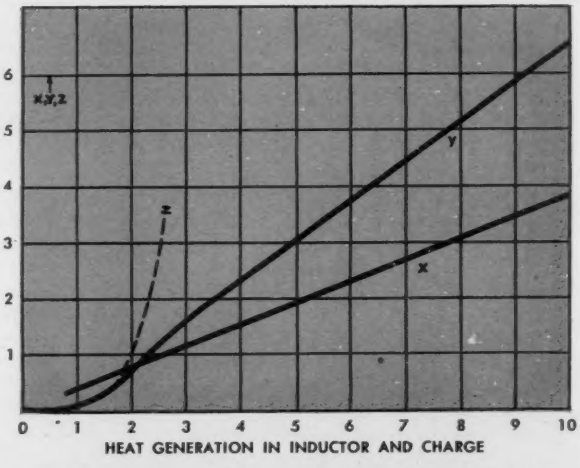
Again, at the outset the rate of heat generation increases with the fourth power of the radius (see curve z, Fig. 3). However, as the radius increases the magnitude of the eddy currents also increases. The increased eddy currents will then noticeably counteract the original magnetic field and thus reduce the total flux inside of the charge. Therefore, the generation of heat cannot be expected indefinitely to increase with the fourth power of the radius. The curve *y*, representing the generation of heat, is bending away from the fourth power parabola (curve z) and asymptotically approaches a straight line.

The copper loss of the inductor is proportional to the length of its winding, and is represented by the straight line x (Fig. 3). Comparing the heat loss in the inductor with the heat generated in the charge, it is evident that the inductor efficiency is poor for small diameters. As the radius of the charge is increased, the heat generated in the charge increases faster than the losses in the inductor, hence the inductor efficiency increases. For still larger diameters the generated heat increases in proportion to the losses in the inductor and the efficiency approaches a constant value.

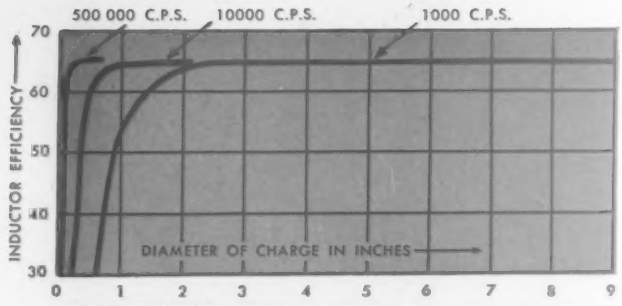
Now consider the inductor efficiency if the frequency is varied and the radii of charge and inductor are kept constant. As previously pointed out, the abscissa axis consists of the product of the radius, a, times the square root of the frequency f. Considering the radius a constant, this same graph can also be used to illustrate the effect of the frequency. As the frequency is increased, the generated heat begins to increase with the fourth power of the square root of the frequency, which is the square of the frequency. If the frequency is further increased, the generated heat increases at a reduced rate, which approaches an asymptote where the generated heat increases only with the square root of the frequency. The losses in the inductor are shown by the same straight line as previously. From this graph we can draw the conclusion that for low frequencies the inductor efficiency is low. As the frequency is stepped up, the efficiency increases, but reaches an asymptotic value which cannot be surpassed, no matter how high a frequency is selected.

In order to illustrate these unusual relations better, the inductor efficiency has been plotted in Fig. 4. It was assumed that the charge is aluminum and has a cylindrical shape, the diameter being equal to the height of the cylinder. It was assumed furthermore that the inside diameter of the inductor is 20 percent larger than the outside diameter of the charge. The efficiency has been plotted for single layer inductors for frequencies from 1000 cycles up to 500,000 cycles and for variable diameters of the charge. The highest attainable inductor efficiency is 65 percent, no matter what frequency has been chosen. However, decreasing the radius of the charge may lead to inductor efficiencies of less than 65 percent. For other metals similar qualitative relations exist.

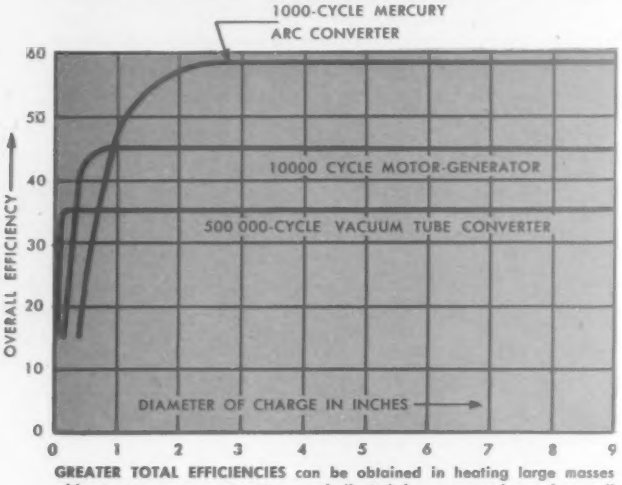
From these curves we can draw the conclusion that there is a limiting highest inductor efficiency. This highest inductor efficiency cannot be increased by a further increase of the frequency. The value of the highest inductor efficiency depends on the material of the charge and its temperature. If the diameter of the work piece is large enough, the inductor efficiency at 1000 cycles is as high as the inductor efficiency would be at any higher frequency.



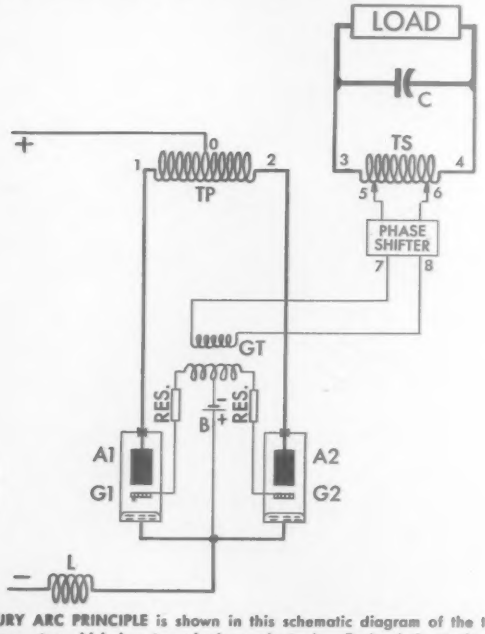
GENERATED HEAT (curve y) and copper loss (curve x) increase at the same rate when radius of charge is increased or when frequency is increased. Hence, inductor efficiency becomes constant. (Fig. 3).



HIGHEST INDUCTOR EFFICIENCY attainable is 65 percent, regardless of the frequency selected, in the heating of an aluminum cylinder, the diameter of which is equal to the height. All metals have a limiting highest efficiency, not increasable with a further increase in frequency. (Fig. 4).



GREATER TOTAL EFFICIENCIES can be obtained in heating large masses with a mercury arc converter, as indicated in a comparison of overall efficiencies obtained by multiplying the average conversion efficiencies of various types of generators by inductor efficiencies in Fig. 4. (Fig. 5).



MERCURY ARC PRINCIPLE is shown in this schematic diagram of the tank type converter which has two single-anode tanks. Each of the tanks has a mercury pool cathode, a main anode and one or several grids. (Fig. 6).

In computing the cost of the electric power consumed by the induction heating equipment, the overall or total efficiency is most important. The overall efficiency is the inductor efficiency multiplied by the conversion efficiency. By multiplying the average conversion efficiencies of the various types of high frequency generators (see ratings on pp. 4 and 5) by the inductor efficiencies (from Fig. 4), these average overall efficiencies are obtained (Fig. 5).

A striking superiority in total efficiency can be obtained by using a mercury arc converter with larger charges, as Fig. 5 indicates. The importance of greater total efficiency is enhanced by the fact that the heating of large masses in itself requires more power, so that the saving in electric power will be still more pronounced. For heating of large masses for melting, forging, annealing, and deep surface hardening, the mercury arc converter provides the most efficient means for induction heating known today.

Mercury arc principle

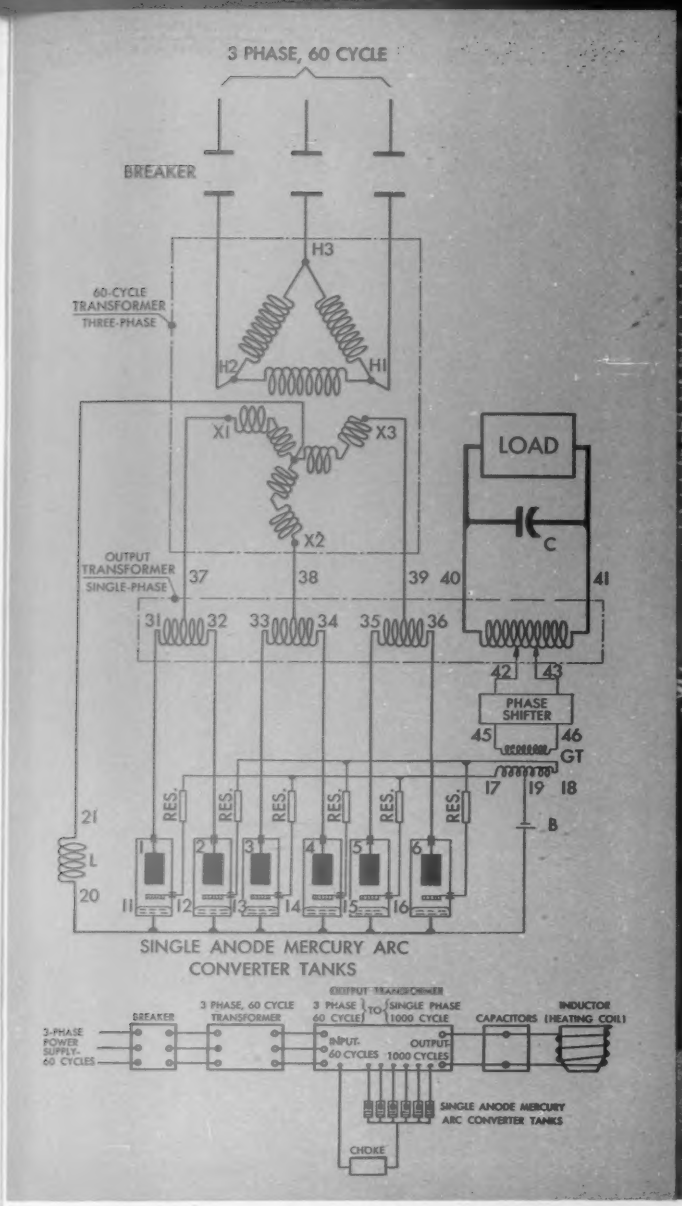
The use of gas or vapor in electronic tubes distinguishes the mercury arc converter from the vacuum tube converter.

Gas or vapor tubes are similar to vacuum tubes as far as their basic electrodes, namely cathode, anode, and grids, are concerned. The introduction of mercury vapor into the discharge path of an electron tube very greatly reduces the voltage drop between anode and cathode, resulting in high conversion efficiencies.

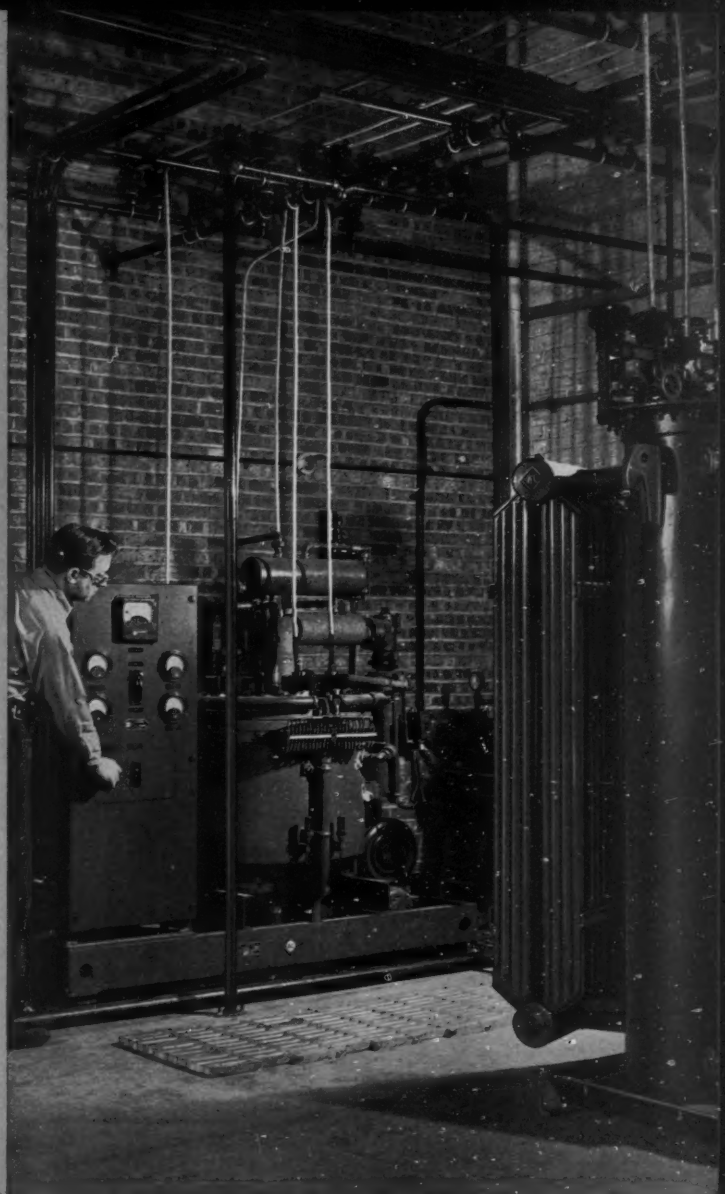
The conduction loss in an electron tube equals the current multiplied by the anode-cathode voltage. In the case of the vacuum tube the space charge effect is responsible for a relatively high anode-cathode voltage drop—therefore, for a high loss inside the electron tube. If vapor, such as mercury vapor, is introduced, electrons may collide with mercury vapor molecules and force orbit electrons out of the atomic shell. This process is called ionization. Having lost an electron, the former mercury vapor molecule, which is now called an ion, represents a positive charge. The field emanating from positive ions defeats the negative field surrounding nearby electrons and thus very greatly reduces the space charge effect. As a result, only a relatively low voltage appears between anode and cathode and the losses inside of the tube are small.

In order to control the discharge, a third electrode, the so-called grid, is introduced. If the grid is sufficiently positive, ionization will get under way and the conduction of current between anode and cathode begins. There is a time lag, known as ionization time, between the instant at which the grid becomes positive and the instant at which a current begins to flow between anode and cathode. As soon as ionization is obtained, the grid loses its control ability and can regain its control ability only after the arc current has dropped to zero and the space in the vicinity of the grid has become deionized.

A prerequisite for the elimination of ionization is the extinction of the anode-cathode arc. When this happens, the ionization does not disappear abruptly, but requires some time, which time is called deionization time. Since it takes a finite time to get the anode-cathode current started by the grid and it takes another interval until the grid can again regain its controlling function, it is obvious that there is an upper limit to the frequency at which a vapor filled electron



DIRECT POWER CONVERSION from the three-phase current, which is conventional on most industrial distribution systems, to single phase is accomplished with this design of mercury arc converter. One pair of the six grid-controlled anodes is always oscillating, so that the secondary of the output transformer will always produce a high frequency voltage. In practice, single-anode or multi-anode converters can be used. (Fig. 7).



ACTUAL INSTALLATION of mercury arc converter for melting by induction is rated 300 kw output at 1000 cycles. Cable connections run from the six anodes of the tank to bushings of the single-phase output transformer, from which cables carry high frequency current to the induction heating application. Meter on the auxiliary control board measure cathode current, excitation current, grid voltages and the vacuum for this unit. (Fig. 8).

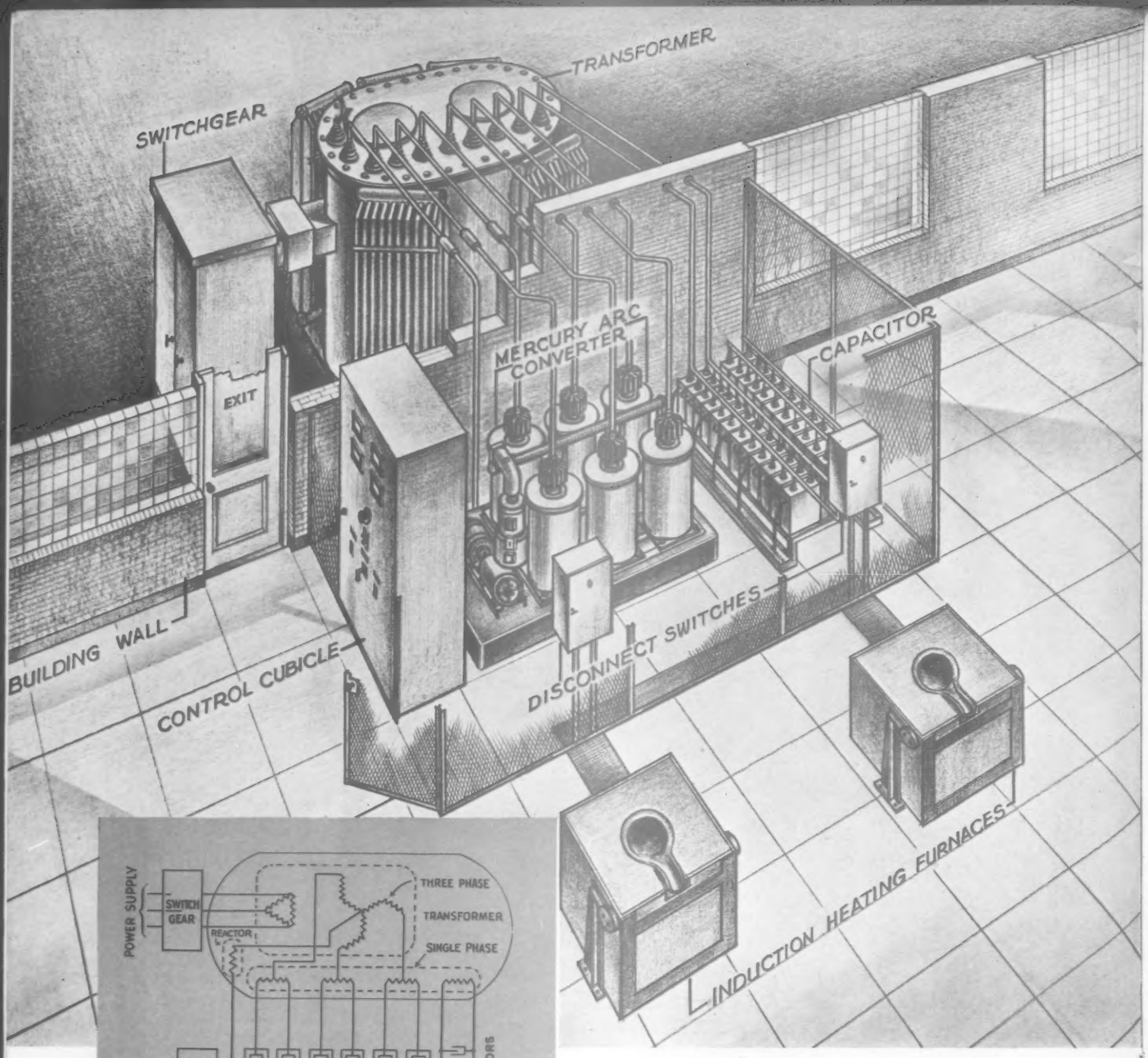
tube can operate. Present day converters operate at frequencies up to 1500 cycles.

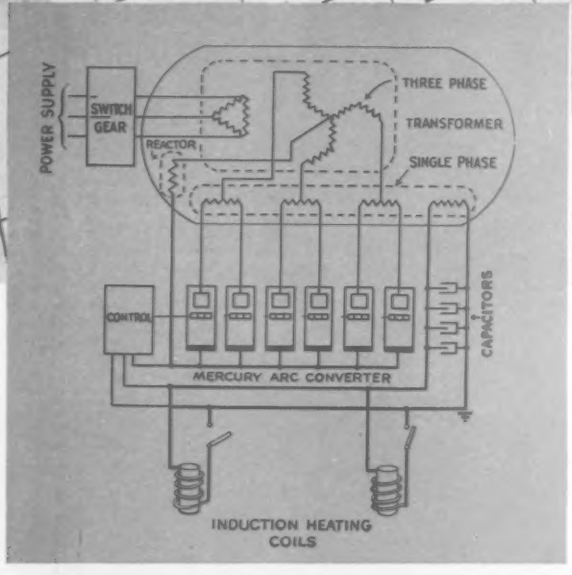
Design of converters

The mercury arc converter operates on a principle which is related to the vacuum tube oscillator in push-pull connection. A source of d-c power energizes the centertap O of the primary of transformer TP (Fig. 6). The ends 1 and 2 of transformer TP are connected to the anodes A1 and A2, which are controlled by means of the grids G1 and G2.

The grid excitation is obtained by feed-back from the secondary TS of the output circuit. A voltage of convenient magnitude is obtained at terminals 5, 6. For proper phase orientation these terminals feed into a phase-shifter whence the grid transformer GT is energized and alternating conduction of anodes A1, A2 results. Currents flowing in alternating directions in the primary TP (from 0 to 1 and 2, respectively) generate an alternating magnetic flux in the transformer core and hence induce the output voltage in the secondary TS.

Single-anode or multi-anode type mercury arc converters may be used. Fig. 6 shows two single-anode tanks, each having a mercury pool cathode, a main anode and one or several grids. In order to start operation an auxiliary starting electrode is provided to automatically ignite the arc. An auxiliary pumping system is connected with the tank in order to maintain the vacuum at all times. Mercury arc

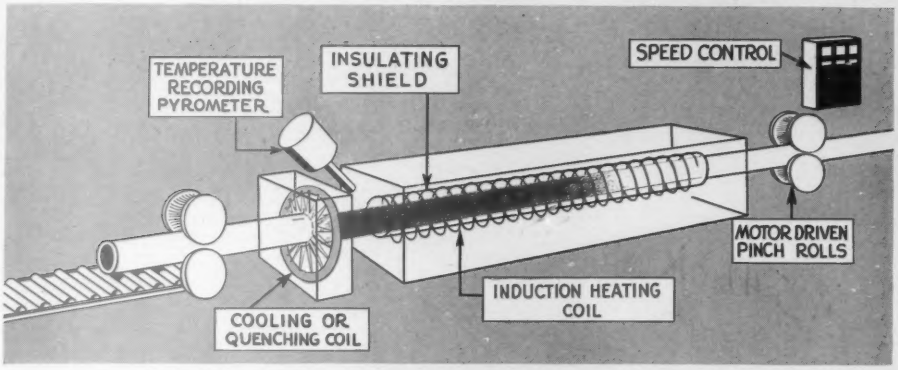




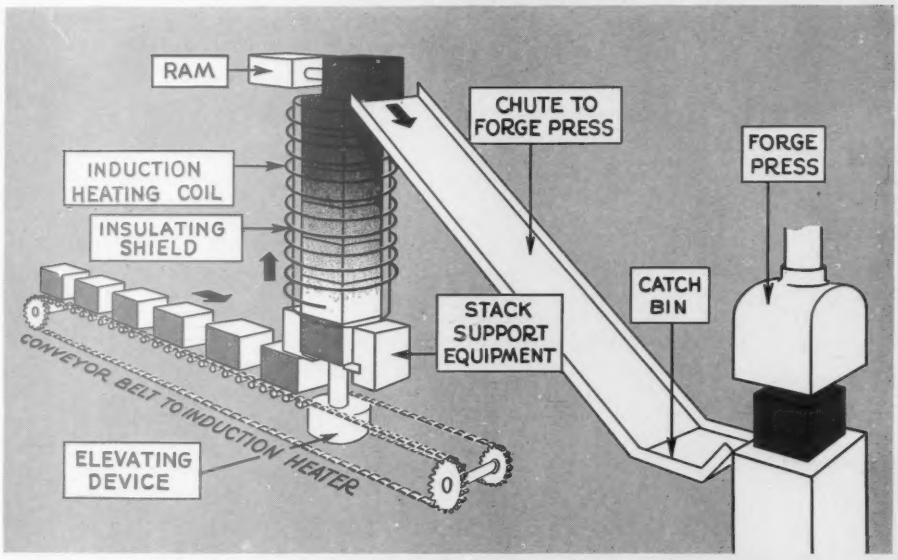
A COMPLETE LAYOUT for induction heating with mercury arc converters is shown schematically here. The outdoor transformer can operate from any three-phase power system, and step-down transformers can be used at some distance from the frequency converter equipment. Converters operate at a frequency established by the heating circuit itself. High frequency power can be distributed throughout a plant in coaxial cables from this centrally-located unit, eliminating problem of handling hot material from a central furnace to several work positions. (Fig. 9).

converters of this type are very similar to the grid-controlled mercury arc rectifiers, which proved to be very reliable over a good many years of service.

So far it was assumed that the input power to the converter is d-c. Since most of the industrial distribution systems use three-phase current, a converter was developed which permits the direct power conversion from three-phase to single-phase. This arrangement is shown in Fig. 7. Each mercury arc converter tank has one grid-controlled anode (1, 2, 3, 4, 5, 6). These anodes are paired in three groups (1-2, 3-4, 5-6) and connected to three groups of primary windings (31-32, 33-34, 35-36) of the single-phase output transformer. The centertaps (37, 38, 39) of the primary single-phase windings are connected to a three-phase 60-cycle transformer whose primary is switched to the 60-cycle supply by means of a circuit breaker.



IN ANNEALING steel tubing, the power input to the coil can be adjusted if the pyrometer indicates overheating or underheating. Induction annealing gives uniformity and a shorter heating time. Furnace warm-up period is negligible and there is almost no scale loss. Time and fuel cost for experimenting with trial pieces can be saved. (Fig. 10).



AUTOMATIC HANDLING saves manpower when steel billets for forging are lifted from loaded conveyor into induction heating coil by hoist at bottom of the stack. As the top heated billet is kicked down the chute to the forging press, another piece is raised from below. Uniform heating permits very accurate duplication, and die life increases with elimination of descaling operation. Arrangement considerably improves working conditions. (Fig. 11).

Color symbolizes degree of heat

During one sixty-cycle interval, the end of each secondary (x1, x2, x3) of the 60-cycle transformer will be positive with respect to the neutral over a period of 120 electrical degrees. During this interval one pair of anodes will be more positive than the rest, and this pair of anodes in connection with the single-phase output transformer will start to oscillate in the same manner as the single-phase converter previously shown in Fig. 6. This oscillation continues as long as this pair of anodes is energized by a higher d-c potential than the other two pairs of anodes.

After 120 electrical degrees, related to the 60-cycle supply, another pair of anodes will be the most positive and this pair of anodes in connection with the single-phase output transformer will start an oscillation of the same frequency and the same amplitude as the former group of anodes did. After another 120 electrical degrees of the 60-cycle, the third pair of anodes takes over and continues to oscillate in exactly the same way as the other two pairs did before. Thus, there is always one pair of anodes oscillating and hence the secondary of the output transformer will always produce a high frequency voltage. The wave shape of the generated high-frequency current is practically identical with a sinusoid.

A commercial mercury arc converter installation —rated 300-kw output, 1000-cycles, 880-volts, with a 2300 volt, 3 phase, 60 cycle power supply—is shown in Fig. 8.

Mercury arc converters are built upward from 250-kw output. At these ratings their initial costs are equal to or lower than all other known high frequency generators. The conversion efficiency is about 90 per cent for a 250-kw unit and will be higher for larger units. Most of the component parts of the mercury arc converter are the same as used in grid-controlled mercury arc rectifiers. The successful operation of mercury arc rectifiers over periods of several decades suggests that the mercury arc converter will acquire the same reputation of being a device characterized by quiet operation, small maintenance costs, great reliability, and very high conversion efficiency.

DEFINITIONS OF SYMBOLS:

a Radius of the charge.
d Distance, point inside charge to surface.
f Frequency of inductor current, in cycles per second.
H Magnetic intensity inside the charge.
i Current density.
p Penetration in centimeters.
r Distance of a point inside the charge from axis, centimeter.
W Generated heat, in watts per cubic centimeter.
μ Permeability, unity.
ρ Resistivity, in ohm-centimeter.

Vacuum Tube Converter
—KEY TO RADIO-FREQUENCY HEATING

J. M. CAGE
Electronic Devices Section, Allis-Chalmers Mfg. Co.

ELECTRONIC oscillators for frequencies above 100,000 cycles per second offer advantages of high power per unit area, accurate control of heating rate and time.

INDUCTION HEATING of metals involves many cases where radio frequencies on the order of 500,000 cycles per second are either preferred or required. As an instance, for surface hardening of steel parts the generation of heat obviously must be confined to a thin skin of the metal, and this requires very high frequencies.

Many other induction heating applications call for radio-frequency power — for reasons that will appear later. For example, objects less than a half inch in diameter almost invariably fall in this classification. The higher bracket of frequencies is also necessary when only small portions of an object are to be processed. And similarly, induction heating of metals having high conductivity are often radio-frequency problems.

Typical of applications that are frequently encountered are these: heating the edge of a saw blade, the joint between two metal pieces. the periphery of a disc. The induction brazing of a silver contact to the head of a copper contactor stud has proved to be a very successful production use. These and many other applications are easily recognized, but in most cases selection of the proper equipment for specific problems should generally be guided by the engineering specialist in induction heating.

While this is a discussion of electronic induction heating, and mercury-arc inverters are also properly known as electronic equipment[1], here we imply high-power vacuum-tube oscillators. For frequencies above 100,000 cycles per second these oscillators have proved to have outstanding advantages.

[1] Mercury arc inverters for producing and applying heating power up to about 1000 cycles per second are discussed by Dr. Storm on pages 7-13.

Electronic induction heating characteristics and advantages can be summarized as follows:

1. Extremely high power per unit area can be applied—as high as 100 kilowatts in one square inch. This characteristic, rather than skin effect[2], is usually the reason for selecting high-frequency heating.

2. Control of heating rate and time is more accurate than with any other rapid-heating process. Once the application is set up for automatic timing with proper handling fixtures, no skilled operators are required.

3. Overall efficiency is approximately 50 percent. This may seem somewhat low in comparison with other electrical generating or converting equipment, but it must be remembered that power is highly concentrated in the metal to be heated; therefore little

[2] See Appendix, page 17.

SILVER CONTACT TIPS ARE BRAZED on copper studs in five seconds in this typical production set-up of the new 20 kw electronic heater.

METAL FITTINGS are brazed (at left) onto sheet metal stampings at rate of 200-250 an hour with standard model 20 kw electronic heater.

heat is wasted in the surrounding air or in adjoining objects. A one-foot length of steel rod, with a diameter of one inch, can easily be held in the hand while one end is being heated white hot with a 20 kilowatt electronic generator.

4. The frequencies employed in electronic induction heating generally are in the range from 100,000 to 500,000 cycles per second. Typical is 400,000 cycles. This frequency is usually high enough to secure adequate power concentrations in small objects; however, in special applications such as the hardening of surgical needles, frequencies higher than five million cycles per second are used. A well-equipped technical laboratory is required to engineer these special applications.

5. Modern electronic generators are rugged, compact, attractive, and entirely self-contained, except for remotely operated control switches.

6. There is practically no maintenance except for electron tube replacement approximately every 5000 hours of use. Tube maintenance cost is not greatly different from power cost.

7. Some cooling means is required for the high-power tubes used to generate the radio frequency power. The smaller units, about five kilowatts or less, use forced-air cooling, but water is usually preferable for large heaters because higher power output from a given size of tube is thereby obtainable. In the large majority of cases, water is also used to cool the applicator or work coils.

Description of equipment

With the appearance of newly designed electronic induction heating units, practical use can now be made of these many advantages. Electronic generators contained in compact, modern cabinets, with the positions of the various components carefully interrelated, have been introduced recently. One unit of this type (illustrated on this page) has a low-loss coupling arrangement which makes it readily adaptable to a wide variety of metal-working problems without the use of radio-frequency transformers.

From the operator's standpoint the new electronic induction heater functions quite simply—he merely pushes the starter button and, when the operation is completed, the unit automatically shuts off. Pre-determined automatic timing controls each unit operation, assuring uniform production quality.

The equipment operates on a-c power (either single-phase for small units or three-phase for large units), which is brought in through a power controlling contactor designed for many thousands of operations. The alternating voltage is stepped up to several thousand volts by the transformer and then rectified to furnish d-c power to the large high-vacuum type oscillator tube. In this tube d-c power is converted to radio-frequency power.

The oscillator is simply an amplifier that feeds itself. The load on this amplifier or oscillator is a resonant circuit consisting of an inductance and a capacitor in parallel, so that an appreciable load impedance is

built up only over a narrow band of frequencies. When a small fraction of load power is coupled back to the control grid of the vacuum tube the circuit reaches a steady-state oscillating condition within that frequency band. The efficiency of conversion from d-c power to radio-frequency power is usually from 50 to 70 per cent.

Power for heating is taken from the resonant circuit, either by direct connection or by inductive coupling.

Applications

Although the fields of application for this new electronic equipment are too numerous to mention, a list of general categories suggests how broad its use can be potentially:

Induction Heating —

1. Surface and deep hardening of gears, splines, shafts, and parts of production items subject to wear.

2. Brazing and soldering of tool tips, contact studs, armature bars, and hundreds of fabricated articles.

3. Annealing of rods, tubing, etc.

4. Melting and forging on a high-production scale of small charges and objects.

Dielectric Heating —

1. Preheating and curing of plastics.
2. Gluing, drying, and curing of wood.
3. Processing of rubber and synthetic materials.
4. Sterilization of foods and medical supplies.
5. Drying and heat treatment of textiles, such as rayon yarn.
6. Processing of chemicals during manufacture.

Besides these applications, the future uses of dielectric heating in the leather, cellulose, chemical, textile, foundry, and other industries, and in sterilization and even cooking of food, look almost unlimited.

Dielectric heating

Because dielectric heating looms so large in the future of electronic equipment, it is probably in order to distinguish between dielectric and induction heating and further describe the former. Induction and dielectric heating have one distinct difference which serves to contrast them. Whereas the main object of induction heating is to *concentrate* heat in a sharply defined locality of a piece of metal, the purpose of dielectric heating is generally to *distribute* heat more or less uniformly in an electrical non-conductor. So, for induction heating we have concentration in conductors, and for dielectric we have distribution in non-conductors.

An an example of dielectric heating, consider the preheating of the urea-formaldehyde type of plastic before placing the material in the mold. Where the mold is intricate or large, it is difficult to heat-soften the interior of the plastic preform before the exterior begins to cure and become non-fluid.

ALL CONTROLS for the new electronic induction heater are mounted behind lockable front panel to prevent tampering; compact, space-saving design is integral part of modern, stream-lined appearance.

In other words, before the center portion of plastic preform reaches proper molding temperature in an oven type of heater, the surface portion often will have been heated too long. This is because heat is applied only to the surface of the preform in an oven, and the interior can become hot only by the slow conduction of the heat inwardly.

However, if a plastic preform is placed between two metal plates and a very high frequency voltage is applied to the plates, heat will be created rather uniformly throughout the mass of the material. Molding times of minutes are in this way cut to as many seconds!

Some non-conducting materials are such poor dielectrics that a frequency of four or five megacycles will satisfactorily heat them. Others may require as high as 100 megacycles. Most, however, can be processed with a frequency in the neighborhood of 30 megacycles. For determining frequency and required power, it is suggested that the application and laboratory services of the equipment manufacturer be relied upon.

As was the case with induction heating, dielectric heating consists in the utilization of a phenomenon that is a serious annoyance to some engineers—dielectric loss within a capacitor—which often causes overheating and destruction of the dielectric. In the process of dielectric heating, as the name implies, dielectric losses within the work are entirely responsible for the heating operation.

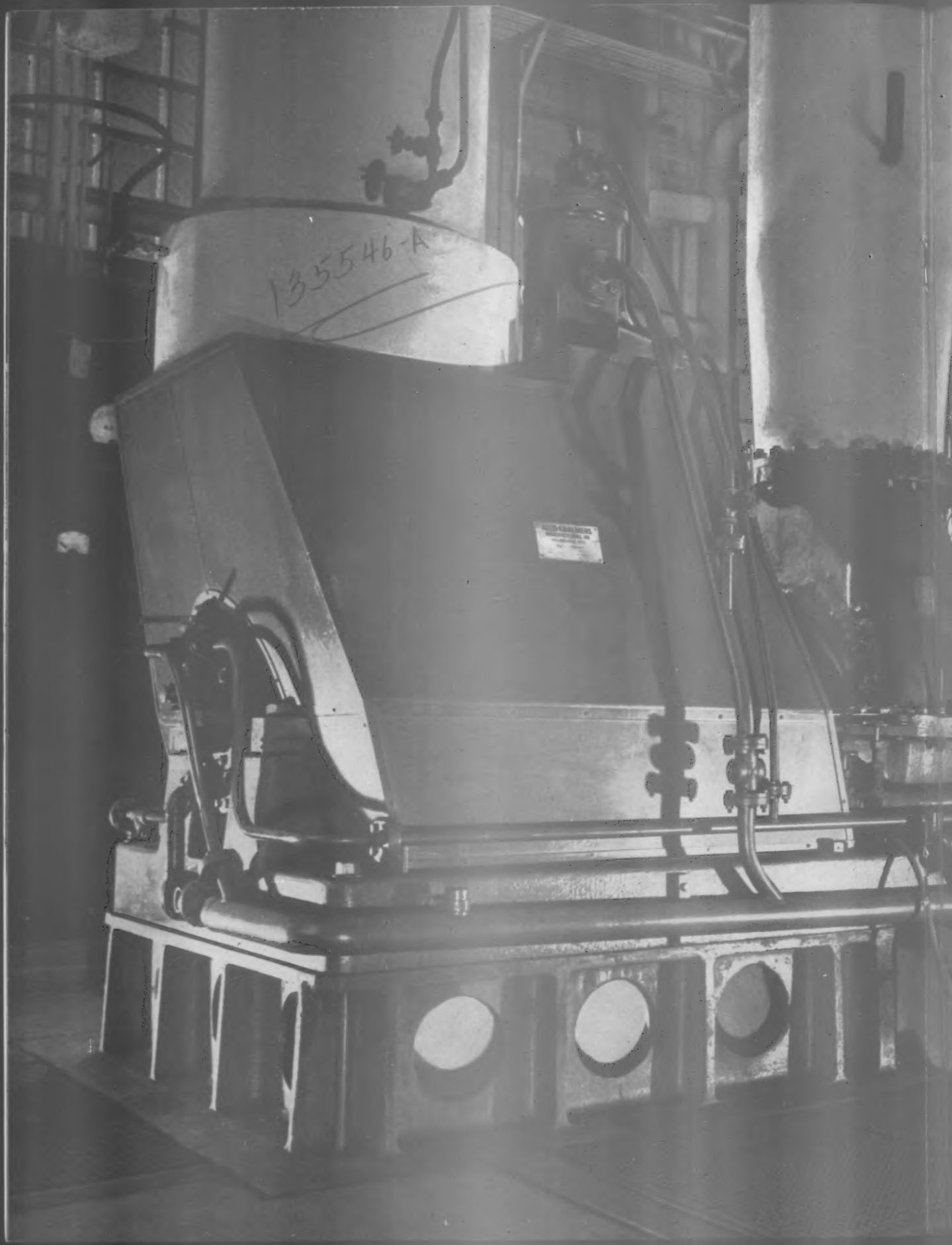
Appendix

In any discussion of the theory of induction heating the phenomenon of skin effect should be understood. Essentially, it is a fact that the higher the frequency the closer the current in a conductor tends to hug the surface.

For example, sixty percent of the current produced by a 400,000-cycle oscillator in a bar of steel below the Curie-point flows within two one-thousandths of an inch of the surface. Both a limitation and an advantage, depending on the application, skin effect naturally influences the selection of induction heating equipment.

Skin effect is most helpful when (a) only the very thin skin of a metal object should be heated, as in the case hardening of steel, or (b) it is desirable to limit heat processing to the edges or corners of even small parts. As an example of the latter case, a small metal ring can be silver-brazed to the periphery of ¾ inch diameter steel disc without warping the center of the disc.

By proper design of the work coil, skin effect can be minimized so that more uniform heating can be obtained. Power is then applied slowly enough to allow the heat to "soak" into the work.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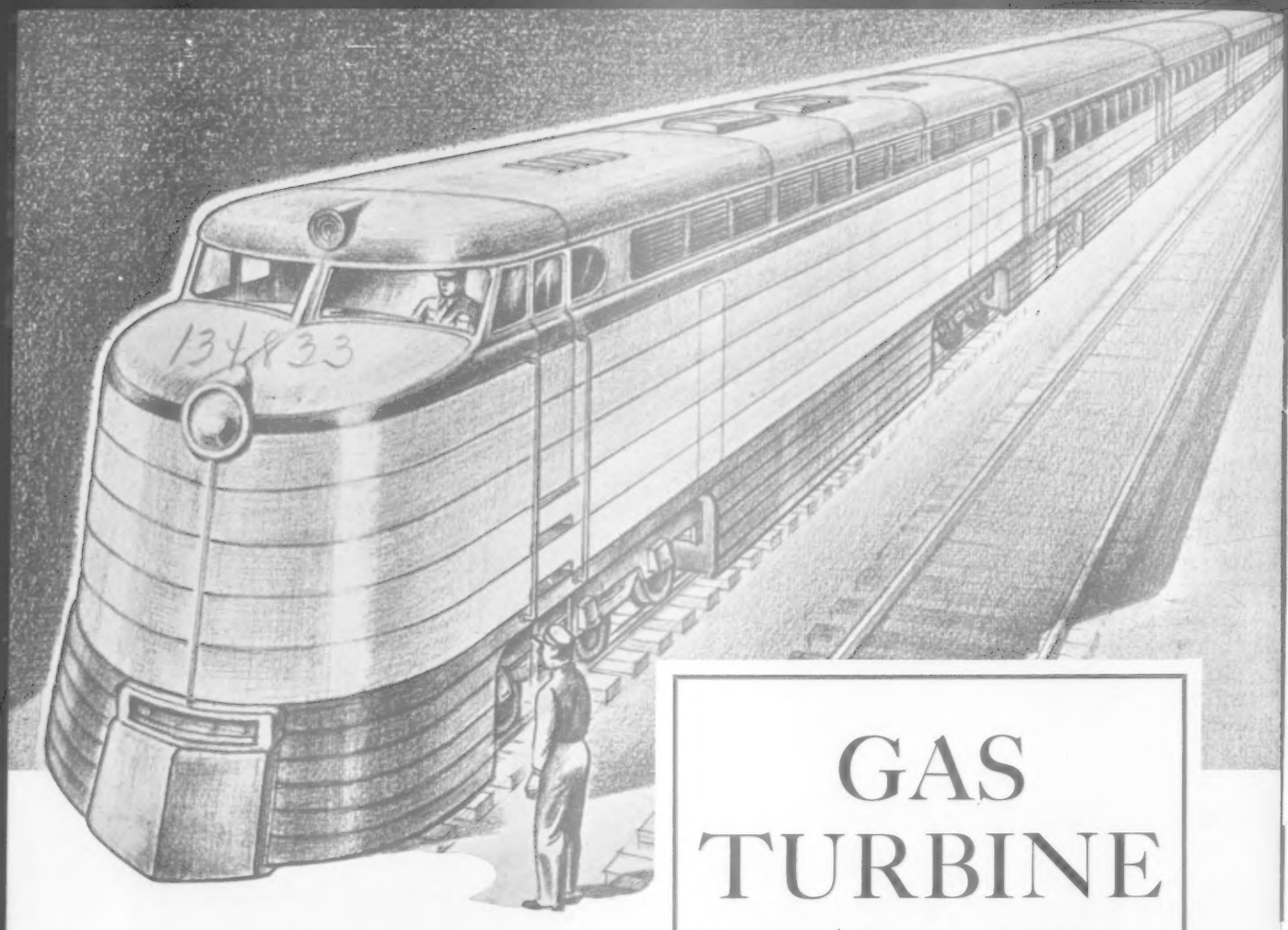

GAS TURBINE

Ready for Rails

PART II

DR. J. T. RETTALIATA, *Manager*
Research and Gas Turbine Development
Allis-Chalmers Manufacturing Co.

SUCCESS of new design for 90 foot locomotive is promised by inherent advantages and latest advances in gas turbine development.

THE thermal efficiency obtainable with the gas turbine locomotive will depend upon the mode of operation adopted, with thermal efficiency and acceleration requirements largely determining the type adopted.

If high thermal efficiency were the only consideration, then maximum turbine inlet temperature should be maintained at all loads. The variation of coupling thermal efficiency with output of one of the 2400 hp gas turbine power plants would then be as shown by curve ADE in Fig. 5. The temperature characteristic would be as indicated by curve ADE of Fig. 6. Operation of this sort would necessitate a proportional reduction in the rotative speed of the prime mover as the load diminished. Curve ADE of Fig. 7 shows that the speed would vary from 5000 rpm at full load to approximately 1500 rpm at no load.

Decreased rotative speeds, however, are undesirable where rapid response is needed because of the time required to accelerate the rotating masses of the power plant before increased output is obtained.

If rapid acceleration were the prime requisite, then the gas turbine unit should be kept running at full speed at all times, with variation in load accomplished by changing the turbine inlet temperature (curve CE, Fig. 7). The turbine inlet temperature, curve CE, Fig. 6, would vary from 1200 F at full load to 740 F at no load for such conditions. With this type of operation, however, the thermal efficiency (curve CE

SUCCESSFUL GAS TURBINE application (see preceding pages) is the now well known Houdry unit helping to produce 100-octane fuel in oil refinery service. Twenty-nine Allis-Chalmers gas turbines are now operating in the Houdry process. The 23,000 cfm unit shown and a 40,000 cfm turbine generate 10,255 hp in a new refinery installation in Ohio.

of Fig. 5, is substantially reduced at partial loads.

The optimum operating condition would be a compromise between curves ADE and CE. Such performance, as determined both by acceptable acceleration and efficiency requirements, is shown by curve BDE, Figs. 5, 6, and 7. In establishing the mode of operation for this condition, the minimum rotative speed was limited to 60 percent of normal. This was adopted to assure reasonable acceleration characteristics, and also to prevent the possibility of "pumping" of the axial compressor, as such a tendency may exist at speeds lower than the minimum selected when the turbine inlet temperature is increased to meet load demands. The speed-load curve is BDE of Fig. 7.

The temperature characteristic, depicted by curve BDE of Fig. 6, was selected to maintain the thermal efficiency as high as possible over most of the load range. Accordingly, the temperature has the maximum continuous value of 1200 F from full load down to approximately 32 percent load, diminishing to 600 F at no load.

The thermal efficiency associated with these speed and temperature characteristics is shown as a function of output by curve BDE of Fig. 5. It can be seen that, from no load to 32 percent of rated output, the efficiency is appreciably better than that obtainable with constant speed operation, but slightly under that possible with constant temperature. At loads greater than 32 percent the efficiency procurable with 1200 F maximum continuous temperature is realized.

It will be noted that in the above three different modes of operation, the thermal efficiency at rated output is the same for all cases, namely, 20 percent at the shaft coupling. Below the rated load the efficiency depends upon the type of operation selected.

Governing characteristics

Having chosen as most desirable the type of operation represented by curves BDE of Figs, 5, 6, and 7 (showing, respectively, thermal efficiency, turbine inlet temperature, and rotative speed as a function of output), a method of governing which possesses performance characteristics suitable for railway application must next be determined. A good governing system primarily requires the maintenance of high thermal efficiency in conjunction with beneficial acceleration characteristics.

There are various ways whereby the gas turbine power plants could be controlled, the difference being in the rate of acceleration. The thermal efficiency under balanced load conditions (curve BDE of Fig. 5) would be the same for all types.

For illustration purposes, in each case let it be assumed that the power plant is operating at point D of Figs. 5, 6, and 7, and it is desired to accelerate from this point. While the maximum turbine inlet temperature has been stated to be 1200 F, a temperature of 1300 F will be used during periods of acceleration, since the time interval is of such limited duration that no harmful effect should result.

Under maximum accelerating conditions, one method of control could, upon movement of the throttle in the direction of increasing speed, immediately increase the temperature to 1300 F while simultaneously raising the output of the power plant in accordance with a predetermined condition. For instance, by means of adjusting the generator field, the output for traction purposes could be maintained in accordance with curve DE, of Fig. 7, as the turbine rotative speed increased. Consequently, since curve DE is based on a constant turbine inlet temperature of 1200 F, the additional energy available with 1300 F goes into accelerating the rotative masses of the power plant. With such a governing arrangement it would require approximately 45 seconds to increase the rotative speed of the power plant from 60 percent at 32 percent load to 100 percent with 100 percent load.

A second type of control system could be somewhat similar to the preceding, except instead of keeping an external load on the power plant, the load would, at the initiation of acceleration when the temperature is increased to 1300 F, be held at a constant value until full speed of the gas turbine unit had been attained. Thus, the output supplied to the traction motors during the prime mover accelerating period would remain fixed, and the excess energy would be utilized in raising the rotative speed of the power plant up to its full value. Regulation of this sort would consume approximately 18 seconds before the rated speed of rotation was attained.

A third and still more rapid method of acceleration would, at the start of acceleration, increase the temperature to 1300 F, simultaneously removing the external connected load from the power plant. This type of control would require the least accelerating time, since the entire gas turbine output at 1300 F would be devoted exclusively to accelerating the prime mover itself. In this instance the actual elapsed time available to the locomotive before rated load would be approximately 8 seconds.

Comparison of the three control methods shows that the first starts increasing train speed at the instant the throttle is advanced, but an appreciable length of time is required before full power is available. The second method maintains constant train speed after the accelerating period has commenced until full load exists on the prime mover, after which the speed of the train is increased. When acceleration is desired with the third method, the train actually loses speed for a short time while the gas turbine power unit is attaining rated load, whereupon full output can be furnished to the traction motors and the speed of the train increased. The time required before rated power can be applied to the locomotive and that required to produce a given acceleration of the train is reduced with each succeeding method of operation.

How control works

Assuming the third method, or variations of it, to be preferable because of its advantageous acceleration characteristics, the means for accomplishing the desired governing could function as follows. To produce an increase in speed an advance of the throttle would (a) introduce more fuel into the combustion chamber to produce up to a maximum temperature of 1300 F at the turbine inlet; (b) reduce the generator field so

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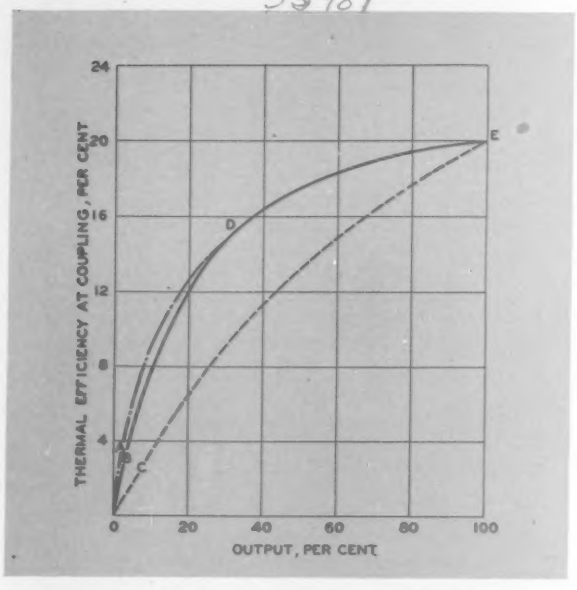

CURVE ADE — Constant temperature (1200 F), variable speed
CURVE BD — Variable temperature, constant speed
CURVE CE — Variable temperature, constant speed

THERMAL EFFICIENCY at the coupling depends upon mode of operation and varies with output of one of the proposed 2400 hp gas turbine power plants as shown by curve ADE (Fig. 5, above left).

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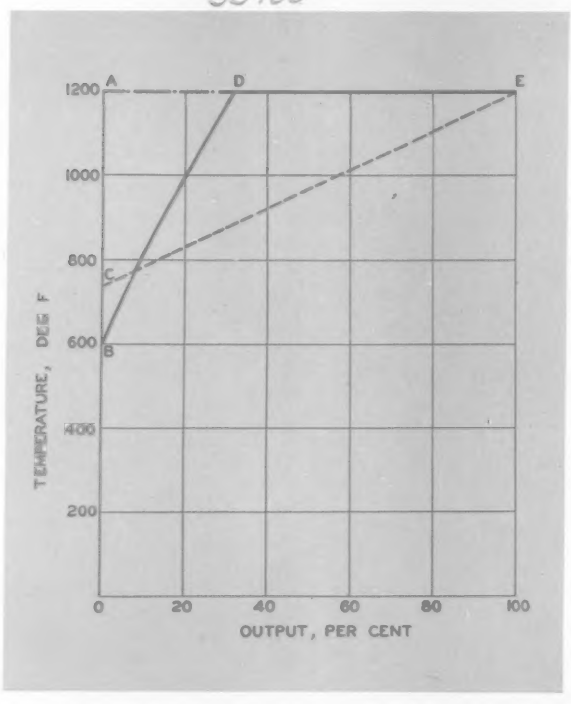

TEMPERATURE CHARACTERISTIC of the locomotive gas turbine is also shown by curve ADE. Highest thermal efficiency calls for maximum turbine inlet temperature at all loads (Fig. 6, above center).

SPEED VARIATIONS from 5000 rpm at full load to about 3000 rpm at no load result in high thermal efficiency, and meet rapid acceleration requirements, as shown by curve BDE. (Fig. 7, at right).

as to remove load from the prime mover; and (c) reset the turbine speed governor by compressing its spring, moving the governor weights closer to the vertical axis of rotation. As the rotative speed of the power plant increased up to its full value, the changing position of the governor sleeve would increase the generator field and reapply external load.

The preceding basic concepts of governing methods pertain primarily to a single power plant but are equally applicable to several.

Performance characteristics

The available tractive effort and rail horsepower characteristics of this gas turbine locomotive are shown as a function of train speed in Fig. 8 by curves A and B, respectively. The tangent level track resistance of the 225-ton locomotive when pulling cars weighing 1000 tons is given by curve C. This curve was calculated on the assumption that the locomotive was hauling 15 cars. The intersection of the tractive effort and resistance curves shows that the 1,225-ton train will have a top speed of 95 mph when travelling on level ground. The starting tractive effort of 85,000 lbs is within the limit of adhesion, assuming a coefficient of static friction of 0.25 for the 225-ton locomotive.

The variation with speed of the rail horsepower required by the train is represented by curve D. The maximum speed of 95 mph may also be obtained from the intersection of curves B and D. With only one gas turbine power unit in operation the maximum power at the rail is 2000 hp, which (referring to curve D) is capable of producing a speed of approximately 70 mph.

Curve E shows the power available at the gas turbine coupling with both power plants in operation. This amounts to 4800 hp at all train speeds. Except in the very low speed range where limitations in traction motor current may prevent the full utilization of the available turbine outputs, the difference between curves E and B is attributable to the transmission losses and the power required to drive auxiliaries.

Curves F to K, inclusive, represent, at ½ percent intervals, the resistance of the 1225-ton train when negotiating grades from ½ to 3 percent, respectively. The intersection of the tractive effort curve A with the various grade resistance curves will give the maximum speeds at which the train can traverse the respective grades.

The speed-time and speed-distance acceleration characteristics for the 225-ton, 4800 hp locomotive when hauling 1000 tons of cars on a tangent level track are shown in Fig. 9.

For a gas turbine locomotive having two duplicate power plants, several general methods of operation are possible. These may be stated as follows:

(a) With one power unit shut down, the load on the other can be increased up to its full value, producing a balanced speed of the train. The speed thus attained will represent the greatest possible with one

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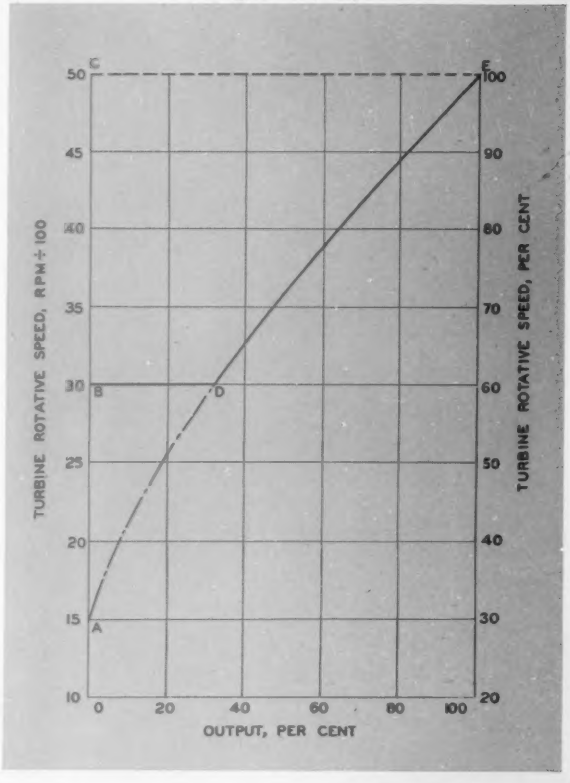

engine operating at rated output. While maintaining full load on the working unit, higher speeds of the train may be reached by starting up the other power plant from a standstill and applying load to it. Maximum train speed will then exist when both units are operating at full power.

(b) Same as the type of operation described in (a), except that instead of the second power unit being shut down completely, it is kept running at all times, idling until the first unit is fully loaded, at which point it is brought in for producing higher speeds.

(c) Both units are operated simultaneously and carry equal loads at all times.

(d) Similar to type of operation described in (c), except that the load may be varied between the two power plants.

Thermal efficiencies

The various overall thermal efficiencies of the 4800 hp gas turbine-electric locomotive referred to the rail for these different types of operation are shown in Fig. 10. Curve ABDE depicts as a function of train speed the variation in efficiency which would occur if type (a) operation were adopted. As was shown by Fig. 8, a single 2400 hp unit is capable of driving the 225-ton locomotive, plus a 1000-ton train of cars at approximately 70 mph. Therefore, portion AB of the curve represents the efficiency with one unit operating and the other shut down. To obtain greater speeds, the second 2400 hp gas turbine is started up and brought in, causing at first a sudden decrease in overall thermal efficiency to D at the transition point owing to its no-load idling fuel requirements. As additional power is extracted, the efficiency increases until it attains a maximum value at E corresponding to full speed of the train.

The thermal efficiency characteristic which would exist for operating conditions (b), (c), or (d) is represented by curve CDE of Fig. 10. Notwithstanding the different conditions of these three types of operation, for all practical purposes they will have the same efficiency curve as indicated. For speeds up to 70 mph, curve AB is higher than CD because under type (a) operation, the absence of idling fuel requirements results in a greater efficiency than for type (b); and the running of the single power unit at a higher proportional rating at a given train speed results in more economical performance than is obtainable with types (c) and (d).

It would be possible to improve the efficiency of type (b) operation if the unloaded unit were idled at the minimum speed possible (approximately 30 percent) instead of at 60 percent, which was adopted for reasons of acceleration. On this basis the thermal efficiency up to the transition point would lie about midway between curves AB and CD. In anticipation of passing through the transition point the second unit could be brought up to proper speed in ample time.

Reference to Fig. 10 reveals the obvious desirability of employing operation of type (a). While opportunities for utilizing this kind of operation may not be too abundant, it should be possible where the character of the roadway, such as numerous curves, etc., prohibits the attainment of speeds in excess of 70 mph for reasonably long periods of time. Where the 70 mph speed point is passed through at fairly frequent intervals, it may be more convenient to adopt one of the other operating conditions as given by (b), (c) or (d), to eliminate the necessity of frequent starting and stopping of the second power unit. It should be emphasized, however, that the favorable efficiency characteristic of type (a) operation can always be realized, even though conditions may prevent advantage being taken of it at all times.

Incidentally, curve CDE is also indicative of the variation of efficiency with speed for a locomotive having a single power plant of the same capacity as the total of the two separate units, namely 4800 hp. This is based on the assumption that the change in efficiency with load of the small and large units is the same, which is not quite the case since the maximum thermal efficiency of the larger unit would be slightly higher because of the benefits of reduced leakage, etc.

Dimensional characteristics

The more favorable dimensional characteristics of the smaller units are significant. Assuming geometrical similarity, the larger unit will have a diameter 41 percent greater than that of one of the half-size machines. Obviously such a dimensional increase

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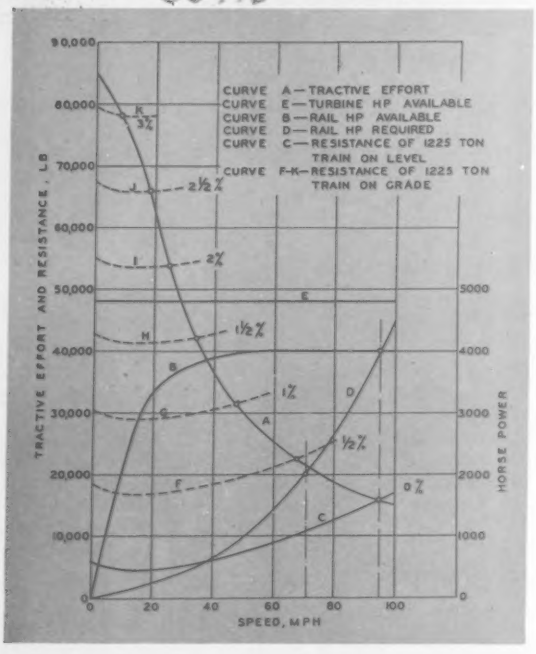
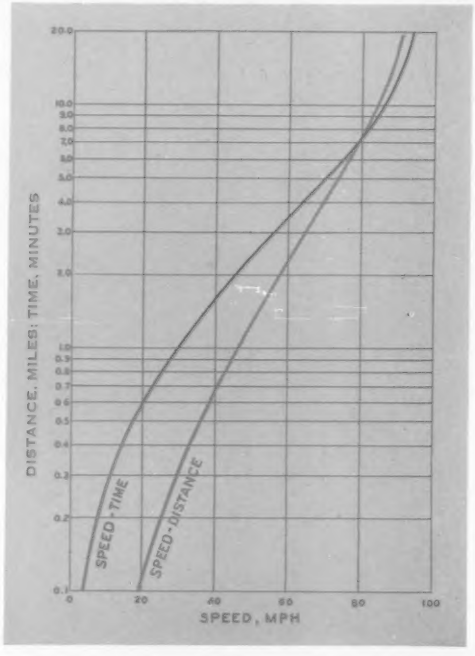
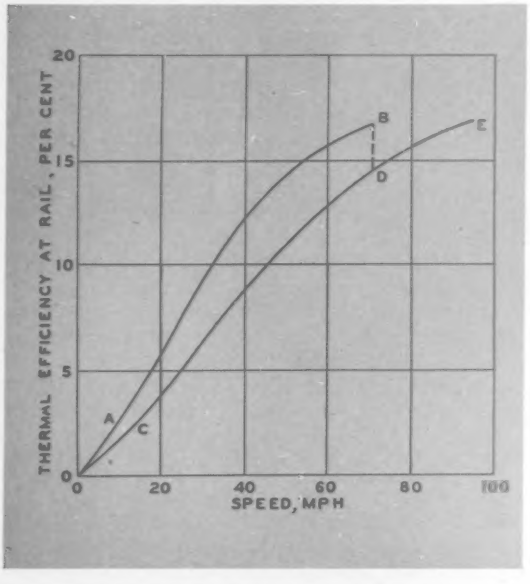

CURVE A—TRACTIVE EFFORT
CURVE E—TURBINE HP AVAILABLE
CURVE B—RAIL HP AVAILABLE
CURVE D—RAIL HP REQUIRED
CURVE C—RESISTANCE OF 1225 TON TRAIN ON LEVEL
CURVE F-K—RESISTANCE OF 1225 TON TRAIN ON GRADE
TRACTIVE EFFORT AND RESISTANCE, LB
HORSE POWER
SPEED, MPH

TRACTIVE EFFORT and rail horsepower characteristics of the gas turbine as a function of train speed are shown by curves A and B, respectively. Curve C represents track resistance (Fig. 8).



SPEED-TIME and speed-distance acceleration characteristics for the 225-ton, 4800 hp locomotive and 1000 ton train on a tangent level track (Fig. 9).



OVERALL THERMAL EFFICIENCIES for various methods of operating a locomotive with duplicate gas turbine power plants. Curve AB represents one 2400 hp power plant, curve CDE represents two (Fig. 10).

complicates the design and makes the installation problem more critical. Furthermore, the large power plant would have a specific weight per unit output 41 percent greater than the two-unit scheme, necessitating larger wheel sizes in order to maintain the same loading per inch of diameter. If it were desired to retain the same diametral dimensions as the smaller units, it would be necessary to increase the rotative speed of the larger machine with accompanying higher stresses and reduced reliability. While it is true that strict adherence to the law of dynamic similitude is not entirely possible owing to certain incidental factors, it is sufficiently close, however, to assure the validity of the above reasoning.

The two-unit arrangement is also desirable in the event of breakdown of one of the units, as the train can still be operated up to 70 mph on a single engine. Servicing of the double engine design would probably be simplified, since it would be easier to remove a smaller, lighter unit through the roof of the cab and replace it with a previously reconditioned engine, placing the locomotive back in operation in minimum time.

In Figs. 11, 12 and 13, which follow, curve ABDE, as previously defined, represents type (a) operation; and curve CDE applies to operating conditions (b), (c) or (d), whichever may be selected.

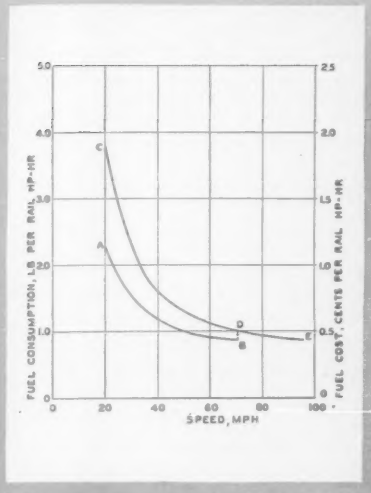
The specific fuel consumption in lb per rail hp-hr for the 4800 hp, 225-ton locomotive with 1000 tons of cars is shown in Fig. 11 as a function of train speed for the various types of operation. The figure also gives the fuel cost in cents per rail hp-hr for the different running conditions. The more economical performance with type (a) operation is apparent from curve ABDE. A fuel oil having an A.P.I. gravity of 16, a lower heating value of 17,790 Btu per lb, a density of 7998 lb per gallon, and a cost of four cents per gallon has been assumed. The selected average cost figure of four cents per gallon is on the conservative side, being higher than the mean of quoted prices on this type of fuel oil which vary from 4.55 cents per gallon for Chicago and 2.28 cents in Argentine, Kansas, in the vicinity of the wells. Thus, the four cent figure is considered equitable and should not yield results partial to the gas turbine.

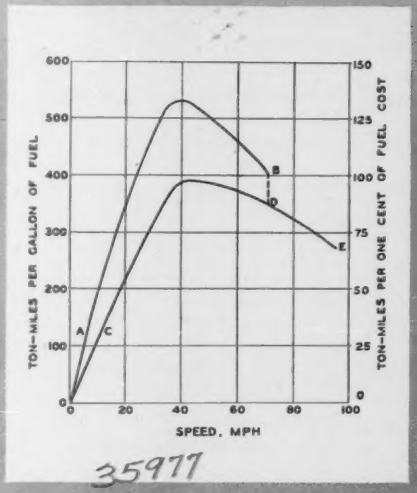
Fig. 12 shows as a function of train speed the ton-

FUEL CONSUMPTION in pounds per rail horsepower-hour and fuel costs in cents per rail hp-hr are shown as a function of speed for various types of power plant operation (Fig. 11, below left).

TRAIN WEIGHT in ton-miles that can be hauled per gallon of fuel and ton-miles per one cent of fuel cost are shown as a function of speed in miles-per-hour (Fig. 12, below center).

FUEL COSTS in cents per ton-mile are indicated for various speeds in the curve at right. Regardless of type of operation, optimum train speed is around 40 mph (at right, Fig. 13).





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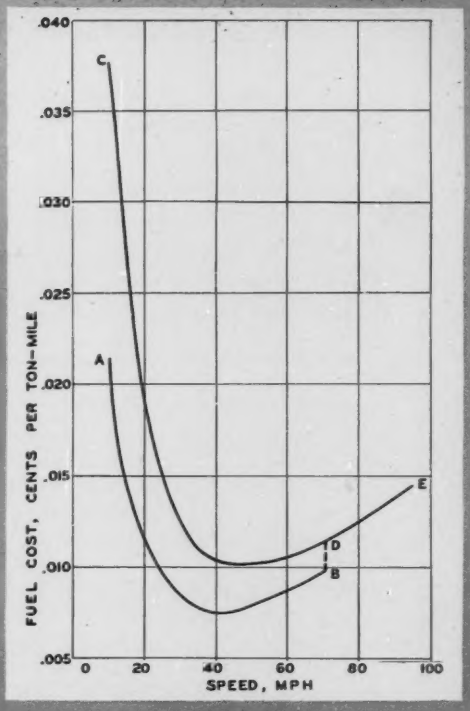


miles of gross train weight that can be hauled per gallon of fuel, and the ton-miles per one cent of fuel cost. Fig. 13 shows the fuel cost in cents per ton-mile at various speeds. In both of these figures it will be seen that, regardless of the type of operation selected, the optimum train speed occurs around 40 mph. Obviously this relatively slow speed could not be adhered to in modern passenger service where fast schedules must be maintained, necessitating operation in the higher speed ranges much of the time. Accordingly, in the interest of favoring the high speed range it will be noted from Figs. 5 and 10 that the gas turbine power units have been designed so that maximum thermal efficiency occurs at their full rated load.

The maximum efficiency of the locomotive referred to the rail is 16.8 percent, occurring at full output of the power plants. The corresponding specific fuel consumption and cost are 0.86 lb and 0.43 cents per rail hp-hr for a fuel having a lower heating value of 17,790 Btu per lb and costing four cents per gallon. The maximum ton-miles hauled per gallon of fuel occurs at approximately 40 mph and amounts to 530, representing a fuel cost of 0.0076 cents per ton-mile. At maximum speed the ton-mile per gallon figure is 275 at a fuel cost of 0.0146 cents per ton-mile. These figures are believed to compare favorably with present practice.

Summary and conclusions

In the foregoing material an attempt has been made to show that the gas turbine possesses characteristics which would be desirable for locomotive applications. The absence of water in the cycle is a natural advantage for railway service. The low maintenance records associated with the oil refinery gas turbines of similar design significantly indicate that service charges on locomotive units will be correspondingly moderate.

As is characteristic with all turbine type equipment, lubrication costs should be exceedingly small, probably less than one per cent of the fuel costs. While it is not possible as yet to use coal as a fuel in the gas turbine, and liquid fuels will probably be employed for a considerable period, experiments with coal for fuel are continuing.

Owing to the large percentages of excess air used in combustion, the exhaust gases will be absolutely clear and free from smoke at all times. Obviously, this is quite desirable. The incentives for the use of dynamic braking are enhanced still further in the case of a gas turbine locomotive since the energy of retardation can be absorbed in the prime mover itself, making electrical resistors unnecessary. If electric train heating is desired, the gas turbine admirably lends itself since the output increases with lowered atmospheric temperatures.

On the basis of developments outlined here, it can be concluded with reasonable certainty that the gas turbine possesses sufficient natural advantages to assure recognition for locomotive applications.

Bibliography

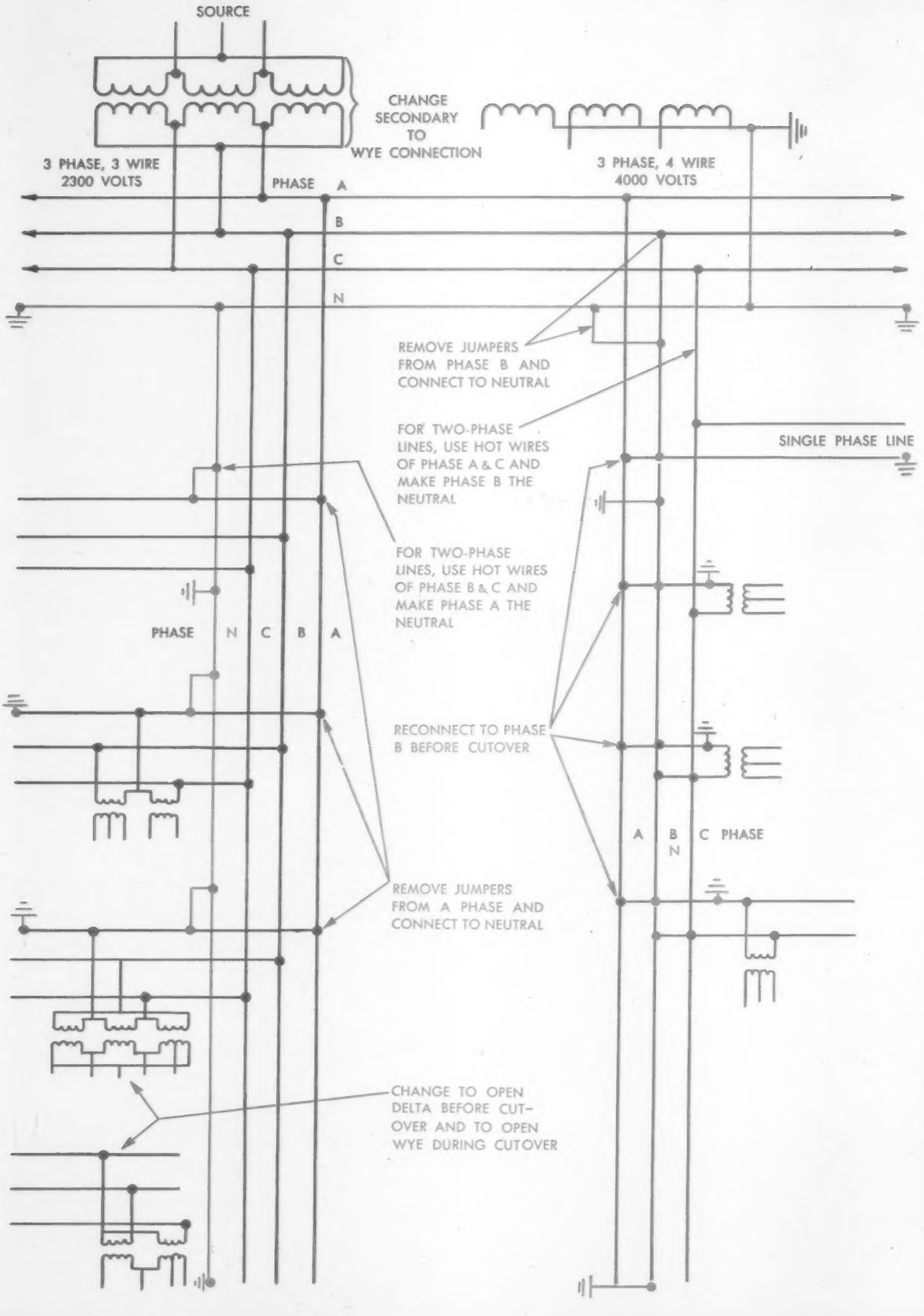
(1) "The Gas Turbine," by J. T. Rettaliata, Allis-Chalmers Electrical Review, Sept., Dec., 1941 and March, 1942; Bulletin No. R-6213, 1942.

(2) "Gas Turbines and Turbosuperchargers," by S. A. Moss, Trans. A.S.M.E., Vol. 66, 1944, pp. 351-371.

(3) "Load Test of a Combustion Turbine," by A. Stodola, Power, Feb., 1940, pp. 62-64.

(4) "Gas Turbine Locomotive with Electrical Transmission," by P. R. Sidler, Mechanical Engineering, Vol. 65, 1943, pp. 261-266.

(5) "Combustion Turbine Locomotive," by J. L. Ray, Allis-Chalmers Bulletin No. B-6066, 1939, 1944.


SOURCE
CHANGE SECONDARY TO WYE CONNECTION
3 PHASE, 3 WIRE 2300 VOLTS
PHASE A
B
C
N
3 PHASE, 4 WIRE 4000 VOLTS
REMOVE JUMPERS FROM PHASE B AND CONNECT TO NEUTRAL
FOR TWO-PHASE LINES, USE HOT WIRES OF PHASE A & C AND MAKE PHASE B THE NEUTRAL
SINGLE PHASE LINE
FOR TWO-PHASE LINES, USE HOT WIRES OF PHASE B & C AND MAKE PHASE A THE NEUTRAL
PHASE N C B A
RECONNECT TO PHASE B BEFORE CUTOVER
A B C PHASE
N
REMOVE JUMPERS FROM A PHASE AND CONNECT TO NEUTRAL
CHANGE TO OPEN DELTA BEFORE CUT-OVER AND TO OPEN WYE DURING CUTOVER

35999

CONVERTING 2300 DELTA TO 4000 VOLT WYE involves preparation of a working sketch showing all changes to be made. Each worker's part of the job should be considered in making specific notations on the conversion scheme.

Quick Conversion Plan Makes System Change Click

Converting an urban electrical distribution system from 2300 volt delta to 4000 volt wye calls for careful planning and layout . . . can then be simple, successful.

B. H. McCOIN

Atlanta District Office, Allis-Chalmers Manufacturing Company

THE preference for 4000 volt wye over 2300 volt delta for urban electrical distribution has become more and more pronounced, and as 2300 volt delta systems become heavily loaded, conversion to 4000 volt wye distribution is frequently considered. While the advantages and disadvantages of 4000 volt distribution (page 28) have been the subject of much discussion, perhaps not enough importance has been attached to the problems encountered after deciding to convert to 4000 volt distribution.

Actually, the process of converting is not difficult, though the job requires systematic planning and careful layout of work to be done.

In cutting over from 2300 volt delta to 4000 volt wye, trouble is likely to occur and "burn-ups" may be caused. This is due to bad insulation in old equipment or accidental grounds which do not show up on the 2300 volt delta system. A preliminary inspection of lines and transformers on the 2300 volt distribution system would reveal some of these conditions, and they could be repaired before converting.

Steps in conversion

The procedure usually followed in converting from 2300 volt delta to 4000 volt wye distribution is:

1. **Determine what section is to be converted.**

2. **Trim trees** to provide proper clearances between wire and trees.

3. **Inspect and repair insulation** of hazardous line and transformer equipment.

4. **Draw sketch of lines to be converted** (similar to illustration on page 29) and include the phase position of wires throughout section, transformer sizes, connections and their location, sectionalizing points, secondary neutrals, ties to other lines, and any other pertinent information.

5. **Determine whether one, two, or three wires and neutral are necessary for the branch or tap lines** (from information on sketch). Ordinarily, two wires and neutral are sufficient and in many cases one hot wire and neutral are ample, depending on the amount of load on the branch line. The latter system allows either the second or third wire to be used as the neutral, thus eliminating stringing an extra wire to act as a ground or neutral wire.

Also, determine where the secondary neutral wire can fill the gap when no extra wire is available to act as neutral. In doing so, use a common ground or common neutral system in which the neutral of the secondary is a part. The common neutral conductor serves as the neutral wire of the primary circuit, the neutral wire of the secondary circuit, and as a grounding wire for connecting grounds, for grounding equipment and for reducing voltage hazards.

At this point these conditions should be carefully checked:

(a) The neutral conductor must be kept continuous at all times and should not be fused.

(b) The neutral conductor must be of sufficient size to carry not only the primary neutral current, but also the secondary neutral current (where there is secondary) and fault currents on short circuits.

(c) All lightning arrester grounds, gap grounds, secondary neutrals, and transformer tanks must be connected to the common neutral.

(d) All pole grounds and anchor guys should be connected to neutral wire. Neutrals should be grounded as frequently as economy will permit and neutrals connected together to form neutral grids, where possible.

Working sketch essential

6. **Prepare a working sketch** indicating (from the above information) secondary neutral ties, extra neutral ties, and balance transformer loads on the circuit (or at least balance connected transformer capacity). This is simply done by tracing phase positions and dividing the connected transformer capacity equally between the phases where it is practical.

The neutral wire and one primary connection of each 2300 volt transformer connected to the neutral should be shown. (Do not get 4000 volts across a 2300 volt transformer; it might work on paper but not in practice!)

Also, show reconnection of all small combination power and lighting transformer banks, and where three transformers are connected in delta, it is advisable to change the size of the transformers and reconnect in open wye. Open delta or open wye connected transformers have approximately 87 per cent of the total capacity of the two transformers on three phase loads, providing both transformers are of the same size.

Ordinarily in a distribution bank of this kind the lighting or single phase load is predominant; therefore, one large and one small transformer is connected in open wye with neutral point grounded. The capacity of the bank in this case is considerably more than 87 per cent of the capacity of the two transformers, since it is obvious that if the single phase load is very large and the three phase load is very small, the capac-

ity of the lighting transformer can be used almost up to its full capacity, thus approaching approximately 100 per cent utilization of transformer bank capacity. The lighting transformers usually should be connected to the leading phase for better voltage regulation.

7. **Lay out all work that can be done before conversion.** This would include stringing extra neutral wire, tying in with secondary neutral, providing jumpers where necessary to tie neutrals together after cutover, putting all transformers and single phase tap lines on correct hot wire and predetermined neutral. Check phase rotation of all three phase power banks to insure motor rotation after cutover. Install extra buses to change substation transformer from delta to wye connection, and add extra feeder voltage regulator if the feeder is regulated. (Three single phase regulators are needed for complete regulation on wye systems.)

If different size transformers are to be used and space is not available on pole before cutover, install the transformers on an adjacent pole if practical, or replace present transformers. Leave all cutouts and arresters connected until conversion to 4000 volts is completed, removing the extra ones later. The neutral wire should not be tied through completely until after cutover and lines have been made "hot." This gives an opportunity to determine what section of the line is in trouble as the neutral is tied into that section. As mentioned before, it is quite likely that there may be insulation failures, possibly in the transformer bushings or in a transformer winding, when connection is made to a grounded neutral system.

Preparation of personnel

After all work is done ahead of cutover, carefully review with your crew the amount of work remaining to be done during the clearance period. A schedule of work should be prepared and written instructions given. Generally it is advisable to supply a rough sketch of changes to be made on each worker's particular part of the job, as well as a notation of where to report when through. (In the event a wrong connection is made, such as picking wrong wire for neutral, it is likely to burn something.) Also, it is essential that one man understand the whole conversion scheme and coordinate all work by the various crews.

After all preliminary work has been completed, the amount of work to be done in the actual cutover is comparatively small. New connections for banked transformers can be made prior to the cutover by inserting cutouts in series with the tap wires or "stingers". Actually, the cutover should consist largely of installing previously planned jumpers to connect neutrals together, the removing of jumpers from phase wires to new neutrals, checking motor rotation at each three phase bank, removing some cutouts where parallel transformers are involved and where lines are converted into neutrals, and reconnecting a few transformers.

8. **Finally, after cutover, check current** in neutral and phase wires at the substation and along main feeder at various branch lines and balance loads. Remove all extra wire, insulators, arresters, cut-outs and put neutral on racks and ground solidly wherever possible. Keep secondaries and primary wires as free as possible from trees. Check size and coordination of sectionalizing fuses for best operation.

Better relay protection with ground relays is sometimes available on a solidly grounded neutral system if the neutral current unbalance is not too great.

In the event the section to be cutover is too large to handle at any one permitted time, auxiliary banks or spare transformers can be inserted and connected in delta to provide enough capacity to take care of part of the load in the section to be cutover at some later time. In the event there are two circuits leaving the substation, those spare transformers (provided they have sufficient capacity) could be connected 2300 volts delta and only one circuit cutover at a time.

In changing over from 2300 volt delta to 4000 volt wye, the problems encountered are not difficult and can easily be solved systematically, step by step. The engineering department requires careful layout and planning of the work to be done, and the line crews must have their work carefully explained to them.

MODERN MOTOR TEST FLOOR (at right), newly constructed, now handles as many as 40 direct-current machines a day. Efficiency tests are made on eleven test bases and rig machines ranging from 10 to 250 horsepower. Tandem testing rig tests four 250 hp motors fully loaded in tandem.

Converting from Delta to Wye Distribution

ADVANTAGES	DISADVANTAGES
1. SAVING IN COPPER. 2. BETTER VOLTAGE REGULATION. 3. LOWER COPPER LOSSES. 4. HIGHER CAPACITY OF DISTRIBUTION LINES. 5. BETTER PROTECTION WITH GROUNDED SYSTEM. 6. LESS HAZARDOUS. 7. LESS EQUIPMENT NEEDED (ORDINARILY). NOTE: CONVERSION itself is simple, economical, requires little new material. For example, wye distribution uses only one arrester, one cutout and one high side bushing for each single phase transformer (delta system requires two of each). Transformer voltage ratings are identical, necessitating only (1) reconnection from delta to wye at main substation; (2) connecting transformers from one phase to neutral.	1. TREE INTERFERENCE IS PROBABLY MORE PREVALENT. (Tree trimming before conversion is recommended). 2. TRANSFORMER BANK CONNECTIONS ARE MORE DIFFICULT. Ground faults can result in blown fuses, damaged transformers. When one fuse blows on the wye-delta bank (which is difficult to determine), overloading and possible damage to the remaining transformers can occur. Faulty regulator operation and primary wire breaks are other sources of trouble. 3. TWO PRIMARY BUSHING TRANSFORMERS REQUIRED for three-phase load. NOTE: They should be about the same size; also, the lighting transformer should be less than twice the size of other transformers with bank. 4. BREAKER HAZARD — more careful handling by linemen required. But proper instruction and training help to reduce the hazard.

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Protect Your Motors from Invasion – *Part* II

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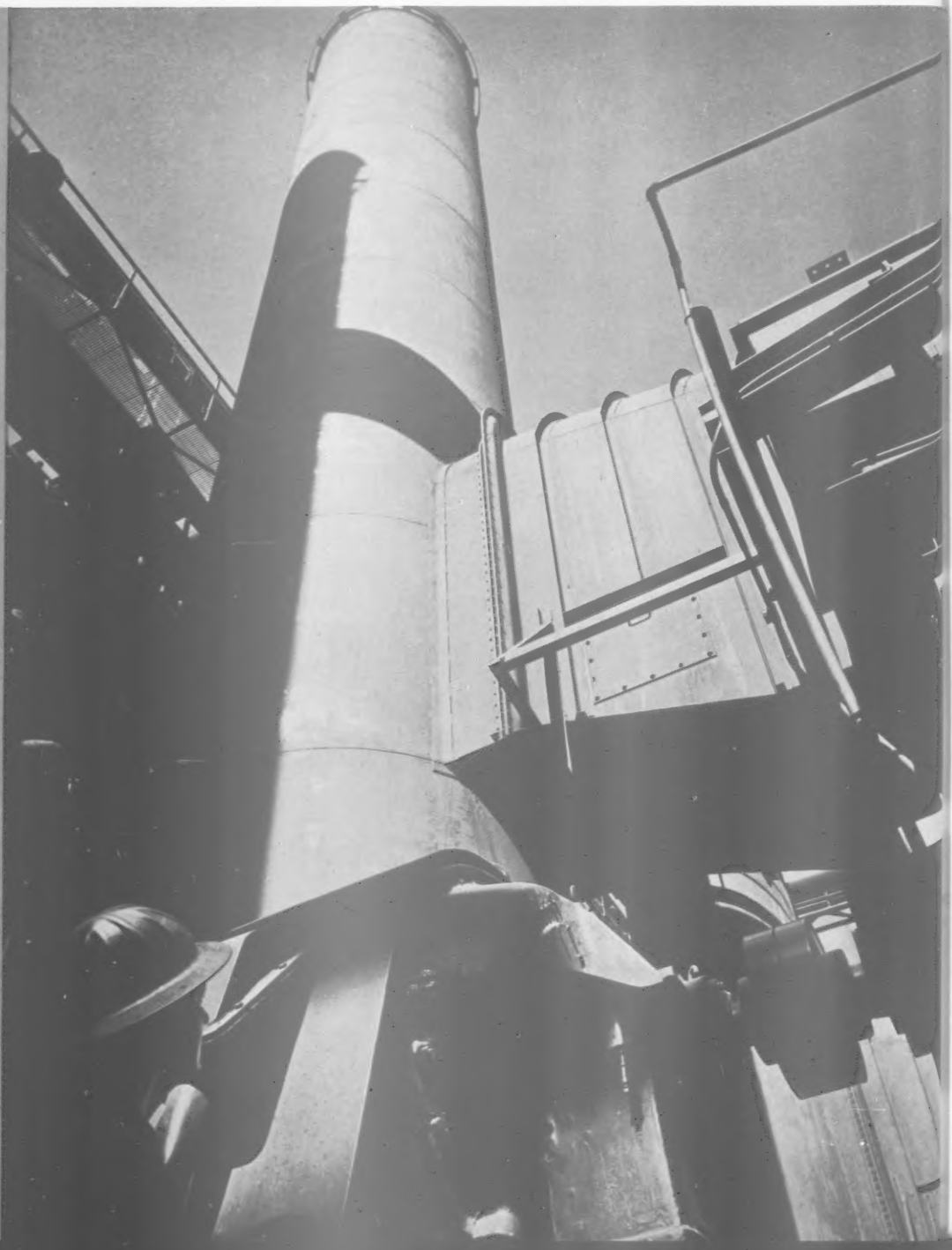


SPLASH-PROOF protection for this blower motor at the base of a powerhouse smokestack in a Texas oil refinery is a guarantee for continuous, uninterrupted service. Rated 400 hp, 1170 rpm, 3-phase, 60-cycle, 2200 volts, it drives forced and induced draft fans on 24-hour-a-day continuous duty.

THOUSANDS of industrial applications have proved that suitable and adequate protection pays off in longer motor life and reduced production interruptions.

ALTHOUGH safety considerations may not be of primary importance in machine design, precautions to assure the safest possible working conditions for the nation's industrial army can and are being built right into thousands of production machines in our war plants. No more common example of this could be found than the "protected features" which are characteristics of standardized electric motor types.

Thus, aside from the economic justification of extra expense for extra protection of the equipment, protection for workmen is a highly important factor, and is, in fact, often guided by various state laws, insurance regulations and building codes.

Accidents and shutdowns caused by objects getting into motors or generators are not uncommon. A motor may be located near the machine tool, for example, where the workman's tools, metal shavings or even the piece being machined might easily fall into it, causing serious damage. A rotating machine may be located in a confined place where material such as bars, rods or lumber is being handled and these objects or tools being used to move the material may accidentally be inserted into the machine. In such cases it is always possible to build fences or wire cages around the equipment, but ordinarily it is more economical to use some form of protective cover as part of the machine itself.

All types of enclosures perform some function of keeping foreign matter from getting into the machine. However, there are three generally accepted types of "protecting" covers:

1. Semi-protected (formerly called "semi-enclosed").
2. Protected.
3. Drip-proof protected.

"Semi-protected" characteristics

ASA defines a semi-protected machine as *one in which part of the ventilating openings in the frame, usually the top half, are protected with wire screen, expanded metal or perforated covers, with openings of certain maximum size. The openings are not to exceed an area of one-half square inch and must be of such shape as not to permit the passage of a rod larger than one-half inch in diameter; except, where the distance of exposed live parts from the guard is more than 4 inches, the openings may be three-fourths of a square inch in area and of such shape as not to permit the passage of a rod three-quarters of an inch in diameter.*

As indicated by the illustration (Fig. 1), the covers of a "semi-protected" motor are made removable to provide access to such parts as the brush rigging on d-c machines or wound rotor induction motors, and are usually bolted to the adjacent machine parts.

The semi-protected type of cover also protects the machine from relatively heavy objects which might fall vertically on the motor.

"Protected" motor features

A "protected" machine (Fig. 2) is one in which all ventilating openings in the frame are protected with wire screen, expanded metal or perforated covers of the same specifications as outlined above for semi-protected machines. This obviously provides more complete protection against any large objects getting into the machine as well as better protection to workmen. It also serves as protection against rodents, which in many localities eat and destroy the coil insulation. While there is no specific standard for "rat-proofness," such protecting covers do offer very good deterrent to the ravages of such creatures.

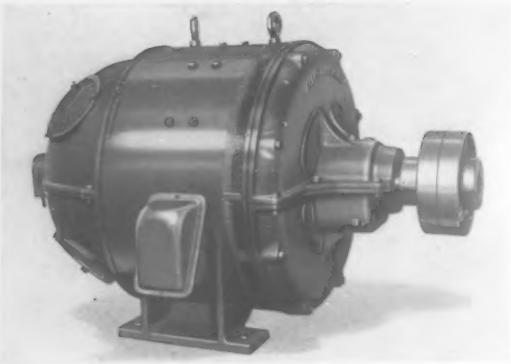
Protection from insects and vermin found in semi-tropical or tropical countries necessitates screens or covers over all openings, generally in combination with special insulation. However, if cover openings less than one-half square inch area are required, it may be necessary, depending upon machine rating and speed, to resort to the totally enclosed type of machine.

"Drip-proof protected" motors

Some installations require a "drip-proof protected" type machine and this construction is simply a combination of the "drip-proof" features with "protecting" covers over all ventilating openings not covered by the drip-proof features (Figs. 3 and 4). The protecting covers must here also conform to the limitations mentioned above for semi-protected and protected machines. This type of construction is used almost exclusively for applications such as underdeck auxiliaries in shipboard service, and even more com-

"SEMI-PROTECTED" MOTOR has removable covers, usually bolted to adjacent machine parts when installed. Parts such as brush rigging are then readily accessible as in this high-speed, squirrel-cage motor (Fig. 1).

In the first part of this series on motor protection (September, 1944, Allis-Chalmers ELECTRICAL REVIEW), drip-proof protection was discussed.



"PROTECTED" MOTOR has *all* ventilating openings in the frame covered with wire screen, expanded metal or perforated covers. This is a direct-current motor designed for a rubber calendar drive. (Fig. 2).

monly in many other places, such as in power stations or on machine tools.

The degree to which ventilation is restricted in these "protected" motor types is fairly well represented by the order in which they have been discussed — semi-protected, protected and drip-proof protected. As previously pointed out, the natural ventilation of a machine is largely governed by the peripheral velocity of its rotor and the imposition of restrictions to the free flow of air through its ventilating passages.

At present, ASA standards recognize a 50 C rise for all machines of general purpose ratings having covers of the types described. This will in general also apply to machines of 200 hp or 150 kw and less for speeds above 450 rpm. However, standards are not complete for ratings larger than general purpose sizes, and in the case of high speed machines, the rated temperatures for open type machines can usually be maintained with the addition of covers of this type.

In cases of larger machines, where a single form of protection is desired for personnel working around them, it is not always necessary to meet ASA requirements for size and area of cover openings, and for such installations the use of heavy wire mesh guard screens are permissible (see Fig. 5). Usually this is done to prevent a person from falling into or touching a live part of a large machine when checking on operation of bearings or wiping off the machine exterior.

"Splash-proof" design for liquids

For protection of the machine itself, the most common type designed to deal with the problem of liquids is the "splash-proof" motor. Many industries, because of unit drives, process arrangement and relatively unfavorable motor location, have of necessity required the use of "splash-proof" machines. They are particularly adaptable for installations where water may fall on or be blown against the machine by a draught or process air, and in plants where floors are cleaned by hosing down periodically, such as laundries, slaughter houses, chemical plants, paper mills, dairies, breweries and mining and milling operations. Motors installed in places like those will usually be part of a process line, so that they must operate satisfactorily under these conditions.

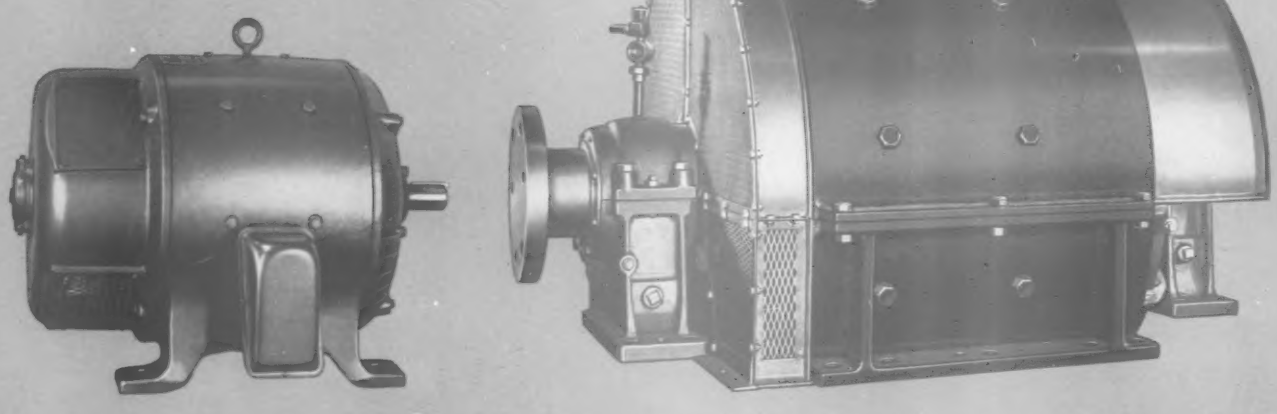
Splash-proof construction goes a step further than drip-proof for machine protection against liquids, as is evident from the ASA definition as follows:

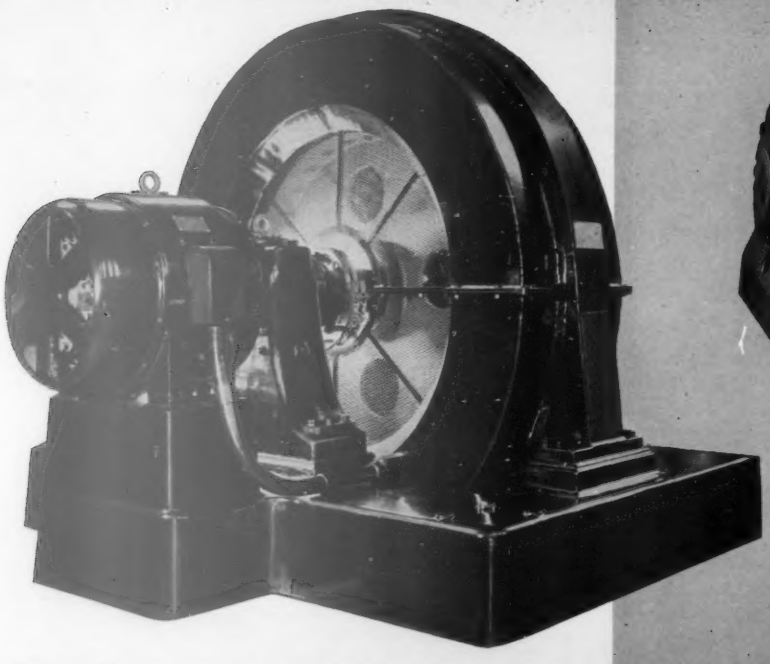
"A splash-proof machine is one in which the ventilating openings are so constructed that drops of liquid or solid particles falling on the machine or coming towards it in a straight line at any angle not greater than 100 degrees from the vertical cannot enter the machine either directly or by striking and running along a surface."

A desirable requirement in the design of splash-proof motors is that the inlet openings be of such proportion as to keep the ventilating-air velocity to a reasonable value to prevent liquid particles from being drawn in by the air stream from the floor or foundation.

The scheme of ventilation is conventional for horizontal machines. In these the air intakes at each end of the bearing brackets and side air outlets at the yoke have their openings well below the center line (see Figs. 6 and 7).

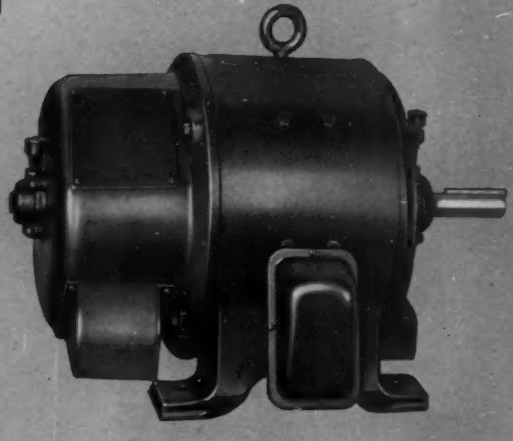
"DRIP-PROOF PROTECTED" motors combine standard "drip-proof" features with "protecting" covers over all additional openings. Common applications are in marine service (two units below), power stations or on machine tools. (Figs. 3 and 4).





GUARD SCREENS of heavy wire mesh are sufficient protection for the ventilating openings of this low-speed, synchronous unit, since safety of personnel is the only factor dictating protective measures. (Fig. 5).

"SPLASH-PROOF" construction for a horizontal machine includes air intakes at each end of the bearing brackets and side air outlets with openings well below the center line at the yoke. This small squirrel-cage induction motor is mounted on a standard NEMA frame (Fig. 6).



SMALL SPLASH-PROOF direct-current motor is designed to prevent liquid particles from being drawn in by the air stream from the floor or foundation (Fig. 7).

With vertical machines, the ventilating air inlets are at each end, top and bottom, and the discharge openings at the sides around the yoke. In larger machines (see Fig. 8), it has been found desirable to bring the air intake and discharge openings down near the level of the supporting yoke feet in order to get the maximum protection. For the latter, therefore, it is necessary to elevate the machine somewhat from the floor or foundation, to allow unimpeded flow of the ventilating air.

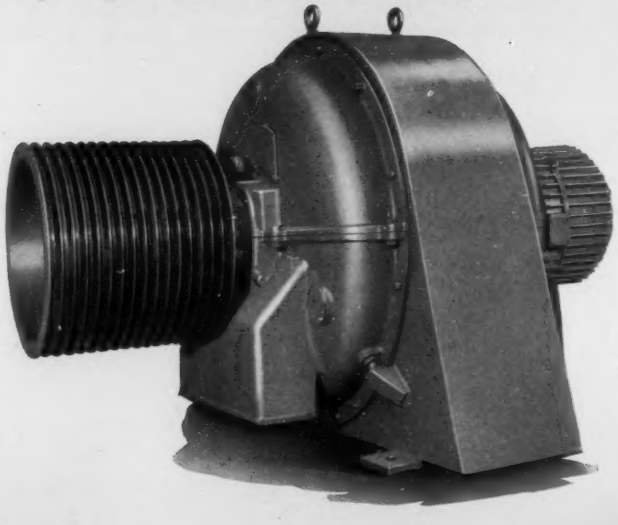
Special outdoor protection

For outdoor service, or where draughts are present, the air intakes and discharge ducts usually will be provided with baffles or deflectors, at nearly right angles to the ventilating air-stream, so that liquids or solid particles cannot enter. Naturally, some moisture (possibly fog in outdoor installations) will get into the machine and be passed through its ventilating system. Some will be deposited upon the core iron and some on the coil insulation. Special care and consideration must be given to the protective coating of the interior of the machines, and an extra protection of moisture-resisting varnish must be given to the coils. The treatment these machines receive during manufacture renders them resistant to moisture and insures a long life expectancy.

Outdoor operation in locations of low ambient temperatures may make the use of bearing lubricant heaters desirable. These may be tied in with the control circuit so that the motor cannot be started until the bearings reach the desired temperature, thus preventing injury to the bearings.

While a splash-proof motor is generally suitable for installation outdoors, obviously there are certain limitations to be considered before it is so installed.

ELEVATED BASE for larger "splash-proof" machines aids ventilation near the supporting yoke feet, where air intake and discharge openings are located for better protection. This is a wound rotor or synchronous unit arranged for power transmission through a V-belt drive (Fig. 8).



Their use for outdoor installations where snow falls heavily and frequently is not recommended. Wet snow may drift and close air intake and discharge openings, or light, dry snow may be drawn in by the ventilating air stream to melt and cause injury to insulation.

Presence of excessive dust or dirt may clog ventilating ducts, or excessive acid or other chemicals may prove injurious to insulation. In many cases it may be necessary to resort to some other type of motor for outdoor installations — for example, either a totally-enclosed or totally-enclosed fan-cooled for smaller sizes, or totally-enclosed with forced ventilation or with air cooler for large sizes.

If the location is such that the motor is subjected to salt-moist atmosphere, the motor should be furnished with non-corroding parts in the case of exposed bolts and nuts, brush rigging, etc., and special moisture-resisting insulation.

Space heaters of sufficient capacity to maintain a motor temperature above the dew point and prevent sweating when it is not in use serve to keep them as dry as possible. They are recommended for locations of relatively high humidity and for outdoor installations where motors or generators may be idle periodically. Their use is limited to ratings of approximately 25 hp and larger. They can be arranged for automatic operation, functioning when the motor is shut down or when the ambient temperature drops to a predetermined value.

"Splash-proof" ratings

The use of splash-proof motors is ordinarily confined to induction, synchronous and direct-current motors, of the bracket bearing type in ratings not exceeding 1 hp per rpm. However, under favorable conditions, and particularly for higher speeds, larger ratings can be built.

Standard splash-proof motors are rated on a 50 C rise continuous basis and without service factor. In warm locations, such as in power plant boiler rooms, or outdoors in the sun, or wherever the ambient exceeds 40 C, a 40 C rise motor should be used. This can be provided in the high-speed class by the use of a larger frame at somewhat higher cost. In the case of low-speed splash-proof motors for operation in an ambient exceeding 40 C, it may be necessary to resort to a full Class B insulated machine (with its higher permissible operating temperature), because the problem of ventilation may preclude the possibility of building an economical 40 C rise machine.

Summary

Protective covers can be incorporated in the construction of any motor or generator. Their design is of such range that they can bring about complete protection from a wide variety of machine-destroying atmospheric and physical conditions and also to personnel working around them. Such protection goes far to insure trouble-free service and does much to extend the life of the equipment. And properly applied, protective covers are very satisfactory, not only because of more efficient operation, but for worthwhile economies in the overall costs of the motor or generator.

New Equipment

Mercury Arc Converter Is Newest Lower Frequency Induction Heater

Development of a new mercury arc converter which fills out the low frequency range of electronic equipment required in the growing field of induction heating applications has been announced recently.

Designed to electronically change power at commercial frequencies of 60 or 25 cycles into 500 to 1500 cycle power, the new mercury arc converter is particularly suited to supplying power for forging, melting, and metal treating applications where large masses of steel or metal parts must be efficiently heated at 200, 500, 1000 and higher frequencies.

Installation operations of a 300 kw unit and a 250 kw unit show performances at higher full load and much higher partial load efficiencies than is possible with other types of inverters for like frequencies and operating and maintenance costs are much lower.

The units are quiet in operation and, being water-cooled, require no ventilation or air-filtering. They offer no vibration problems, eliminating heavy and expensive foundations. Minimum rating of the unit will melt 800 pounds of steel per hour, while higher ratings will melt several tons per hour. Details are available in new bulletin B6373.

New Vacuum Tube Induction Heater Works At High Frequencies

Newly developed for highest frequency induction heating is a compact, streamlined, 20 kw electronic induction heater of the vacuum tube type. Operation at frequencies from 400,000 to over 10,000,000 cycles is possible.

With a low-loss coupling arrangement, this generator can be adapted to brazing, soldering, annealing, hardening and pre-forge heating applications without the use of radio-frequency transformers. Predetermined automatic timing controls each unit operation, assuring uniform production quality.

Featured, also, are a current limiting circuit for protecting the oscillator filament and prolonging tube life; a three-phase rectifier on larger size units to obtain maximum power and prevent unbalance of the power line; and safety devices for full protection of operator and unit. The unit is available in capacities of 1 kw to 200 kw, and all models having a capacity of 10 or more kilowatts operate from either 220 or 440 volts, three phase supply. For more complete information, write for bulletin B6372.

COMPARE REGULATORS FOR 2400 V. FEEDERS

Important economies and superior operating characteristics of the 5/8% Step Regulator are explored in the comparison chart below.

FEATURES	INDUCTION-TYPE REGULATOR	ALLIS-CHALMERS 5/8% STEP REGULATOR
Low Exciting Current?	NO Three times that of Step Regulator.	YES A third that of Induction Regulator.
Savings in Initial Price?	NO Both regulators cost the same initially.	NO Regulators cost the same initially.
Investment Economy?	NO High exciting current means kva diverted from revenue-producing loads ...cost of capacitors to balance wattless current is high.	YES Low exciting current means more system kva available for useful loads . . . cost of capacitors to balance wattless current is low.
Quiet Operation?	NO Core slots, rotor bearings, air gap are possible causes of noise.	YES Regulator has no more audio noise than equivalent transformer.
Flexibility of Current Rating?	NO Gives ±10% regulation at rated current and ±5% regulation at double the current value.	YES A-C regulator gives ±10% regulation at rated current, and ±8¾%, 7½%, 6¼% and 5% regulation at higher current values.
Close Regulation?	YES Voltage held within 1% (1 volt). Holding coil adjustments, tendency of motor to overshoot make perfect regulation difficult.	YES Voltage held within ¾ volt by 5/8% step regulation with Feather-Touch control.

A 1823

Get the full story on the DFR 5/8% Step Regulator for low voltage feeders in Bulletin B-6065, ALLIS-CHALMERS, MILWAUKEE 1, WIS.

ALLIS-CHALMERS *5/8% STEP REGULATORS*

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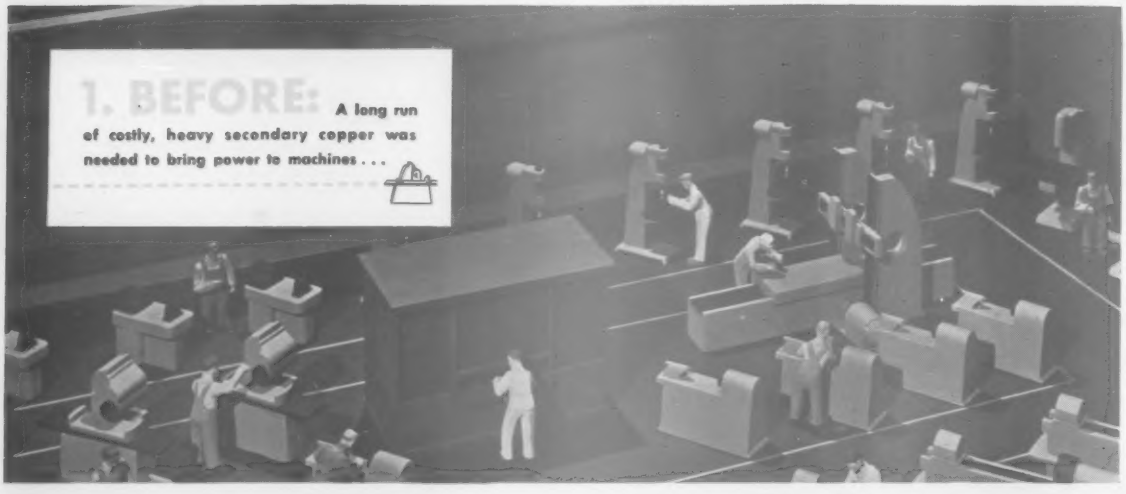
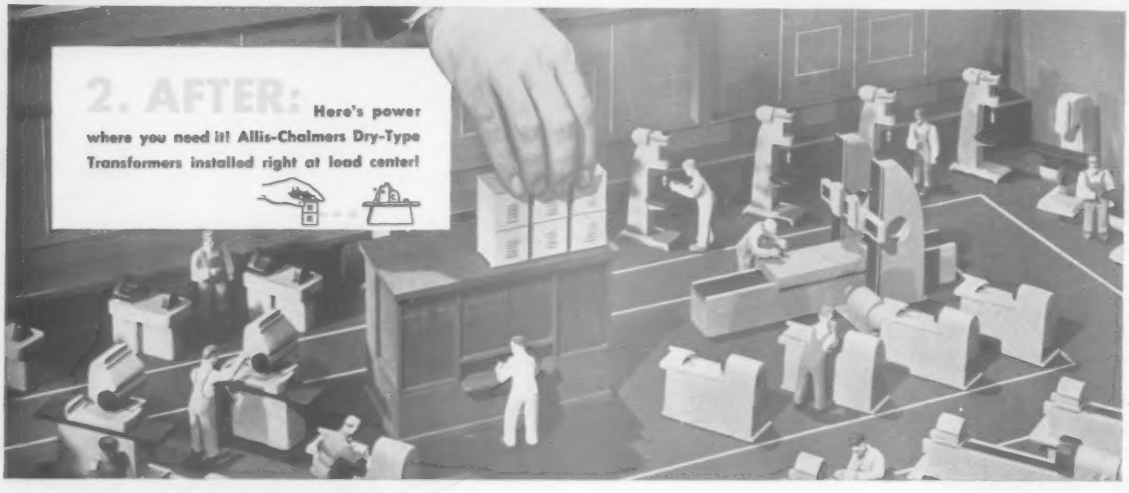
MR. E. A. BARTLEY
STEAM TURBINE DEPT.

Here's the Easy Way

TO STEP-UP MOTOR AND LAMP PERFORMANCE!





CONTRAST THESE TWO PICTURES. No. 1 shows a condition of *poor* lighting and motor performance. This is a result of line losses and low voltage incurred over a long run of heavy secondary copper bringing power to the machinery being served.

Now look at picture No. 2. By installing 3 Allis-Chalmers AD Dry-Type Transformers *right at load center*, motor and lighting performance have been *stepped up!* That power consuming run of secondary copper is *eliminated*. Man-hours and materials were *saved* . . . no insulating liquid or fireproof vaults were needed.

And because Allis-Chalmers AD Dry-Type Transformers are 1) small, 2) light, 3) won't drip, they go up *anywhere* . . . on posts, beams, overhead structures. Get full details on these highly adaptable, money-saving units today. Send for Bulletin B6027. ALLIS-CHALMERS, MILWAUKEE 1, WIS.

A 1832

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